REPORT NO. DME/NAE 1972(1)

NATIONAL RESEARCH COUNCIL OF CANADA

QUARTERLY BULLETIN OF THE DIVISION OF MECHANICAL ENGINEERING AND THE NATIONAL AERONAUTICAL ESTABLISHMENT

OTTAWA

1 JANUARY TO 31 MARCH 1972

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FOREWORD

The Quarterly Bulletin is designed primarily for the information of Canadian industry, Universities, and Government Departments and agencies. It provides a regular review of the interests and current activities of two Divisions of the National Research Council of Canada:

The Division of Mechanical Engineering
The National Aeronautical Establishment

Some of the work of the two Divisions comprises classified projects that may not be freely reported and contractual projects of limited general interest. Other work, not generally reported herein, includes calibrations, routine analysis and the testing of proprietary products.

Comments or enquiries relating to any matter published in this Bulletin should be addressed to: DME/NAE Bulletin. National Research Council of Canada, Ottawa, mentioning the number of the Bulletin.

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AERODYNAMIC AND STRUCTURAL NOISE RESEARCH AT NAE

R. Westley, G.M. Lindberg

Structures and Materials Laboratory

and

Y.Y. Chan, B.H.K. Lee

High Speed Aerodynamics Laboratory

National Aeronautical Establishment

INTRODUCTION

Unsteady aerodynamic flow processes radiate sounds that are known as aerodynamic noise. Aerodynamic noise becomes most intense when it is generated by high subsonic or supersonic flows. Thus we may expect intense sources of noise to be found in high speed jets, compressible flow boundary layers and high speed rotors.

Noise generated by aircraft continues to pose both complex technical and serious social problems. Its reduction is becoming an increasingly critical factor in the design of future aircraft:

(i) many of the present CTOL aircraft exceed the socially acceptable noise levels in wide areas that extend up to 50 square miles around major and minor airports;

(ii) the operation of V/STOL aircraft near city centres depends directly on the development of an aircraft with noise levels that are considerably below those of present CTOL aircraft;

(iii) overland flights of SST transport aircraft are currently banned in many countries and the economic usefulness of the SST will remain limited unless ways of reducing the effects of sonic booms are found;

(iv) military aircraft, especially the slower moving types such as helicopters, will have tactical advantages if they are able to approach unheard;

(v) aircraft structures are often damaged when subjected to high intensity acoustic environments. This damage problem is becoming more critical with the growing utilization of lightweight construction, especially for V/STOL aircraft;

(vi) aircraft fuselages have to be designed so that the internal noise is maintained at, or reduced to, comfortable levels;

(vii) there are a variety of less obvious unsteady aerodynamic processes that may be excited by, or self-coupled to, aerodynamic noise. For example, aerodynamic noise may alter the boundary layer transition point on a wing or body which in turn alters the steady aerodynamic forces;

(viii) the applications of aerodynamic noise research extend into a wide range of non-aeronautical fields such as motor car wind noise, ventilation systems, fluidic controls, valve noise, flow noise problems in nuclear power stations, etc.

DEFINITION OF AERODYNAMIC NOISE

Aerodynamic noise may be defined as the pressure fluctuations which are radiated by unsteady aerodynamic flow processes. These aerodynamic flows include: free shear layers such as those found in wakes or jets; turbulent boundary layers; oscillations or breakdowns of laminar boundary layers; separated flows; unsteady flows over cavities; oscillating bodies or moving surfaces in fluid flows; buffeting flows; the shedding of vortices; the breakdown or bursting of vortices; oscillating shock waves; turbulence, sound and entropy interaction with shock waves; combustion noises; the impingement of wakes or oscillating flows upon solid bodies; the translation or rotation of pressure fields fixed to a moving body. In many cases, progress in aerodynamic noise research is dependent on a fuller understanding of the accompanying unsteady aerodynamic processes.

The aircraft structural designer has a direct interest in the steady and unsteady surface pressures produced by aerodynamic processes. Experience on many different aircraft has shown that the high frequency low amplitude pressure fluctuations associated with a jet exhaust can cause structural fatigue failure in regions close to the jet, or in the area of jet impingement. Similar failures have occurred in other regions of pressure fluctuations such as close to propeller tips and in regions of separated flow, as for example behind airbrakes.

VALUE OF NOISE RESEARCH

The cost benefits of noise research are difficult to evaluate but, in the case of V/STOL aircraft, it is now clear that an otherwise very successful aircraft may be unsaleable if it does not meet very restrictive noise limitations. Methods of engine noise reduction generally involve loss of thrust, weight increases and additional fuel consumption. All these contribute to a reduction of payload; hence an increase in operating costs. At present, each one PNdb of noise reduction involves a thrust loss of $\frac{1}{2}$ to 1%. As well, there are the additional capital and operating costs of the noise reduction devices. As an example, the proposed retrofit of DC8's and 707's to reduce noise levels by about 1-3 PNdb's on take-off and from 6-10 PNdb's on landing, is estimated to cost approximately $1 million per aircraft.

While there are no known cases of catastrophic failures of aircraft due to acoustic fatigue, damage to structures can lead to unacceptable expenses for maintenance and inspection. As well, the designer strives to achieve greater fatigue resistance for more severe loadings, while simultaneously reducing the weight of vehicle components. Any laboratory work that leads to better, lighter structures directly contributes to improved payload and lower operating costs.

The methodology to cost the ecological damage from CTOL aircraft has not been fully developed but various estimates suggest that real estate properties with noise levels above 95 PNdb could be worth approximately 10% less than similar properties in quiet surroundings. Estimates of noise damage for a large airport vary between \$20 million and \$500 million depending on the location. If one assumes that the noise damage in Canada is equivalent to that from five large city airports and that a 25 PNdb noise reduction is necessary to fully eliminate noise damage, then the environmental benefits would be approximately \$50 million per 1 PNdb of noise reduction (costed over a 20-year period).

Past experience in aerodynamic noise research suggests noise reductions of 0-5 PNdb are those most likely to be achieved, 5-10 PNdb are difficult but not impossible, 10-20 PNdb are extremely difficult, and 20-30 PNdb are almost impossible.

NOISE GROUP

The National Aeronautical Establishment has maintained a continuing interest in noise research since its formation. Following early ad hoc studies[1 to 6] the Structures and Materials Laboratory established a special Acoustic Test Facility in 1965[7,8,20]. This laboratory satisfied several of the recommendations of the NRC Associate Committee on Aircraft Noise[9] and was specifically designed for near field noise studies, structural response and acoustical fatigue studies, sound transmission loss and noise attenuation studies and aerospace environmental military specification testing. Such studies aid the aircraft designer who must specifically meet the Sonic Fatigue Requirements of FAR25, FAA Regulations for Transport Category Airplanes[10]. Its efforts have been supported by the NRC Associate Committee on Aeronautical Structures and Materials (see Ref. 11, 12 for example) and Laboratory staff have actively participated in the AGARD Structures and Materials Panel Collaborative Program on Acoustic Fatigue Data Sheets (see Ref. 13, 14 for a summary of AGARD interest).

Since 1965, research efforts have centered on structural response (see Ref. 15, 16, 17, 19, 27, 29, 37) and shock cell noise[21,23,25,28] as well as ad hoc testing for laboratory improvements and outside agencies[18,22,24,26]. During the past year, however, research on noise has been augmented with the co-operation of the High Speed Aerodynamics Laboratory. Y.Y. Chan, B.H.K. Lee and A. Gault have contributed additional expertise on steady and unsteady high speed aerodynamic processes to complement the expertise on structural response and aerodynamic noise contributed by G.M. Lindberg, R. Westley, and J.H. Woolley.

The Acoustic Test Facility and the Hypersonic Laboratory are housed in the NAE 5-foot Trisonic Wind Tunnel building and a large source of air, compressed to 20 atm., is readily available from the wind tunnel's storage bottles. Figure 1 indicates the general layout of the facility.

The expanded effort has permitted a number of theoretical and experimental projects connected with aerodynamic noise to be initiated[34,35,38,39,41,42,43]. These recent investigations have demonstrated that, in the general case (the supersonic jet), there are at least three different types of noise, namely, turbulence noise, Mach wave noise, and shock cell noise. Under different operating conditions of the nozzle, one of the three types of noise may predominate but, in general, they are all present and may be strongly coupled. In order to propose a realistic model for the noise field of the jet,

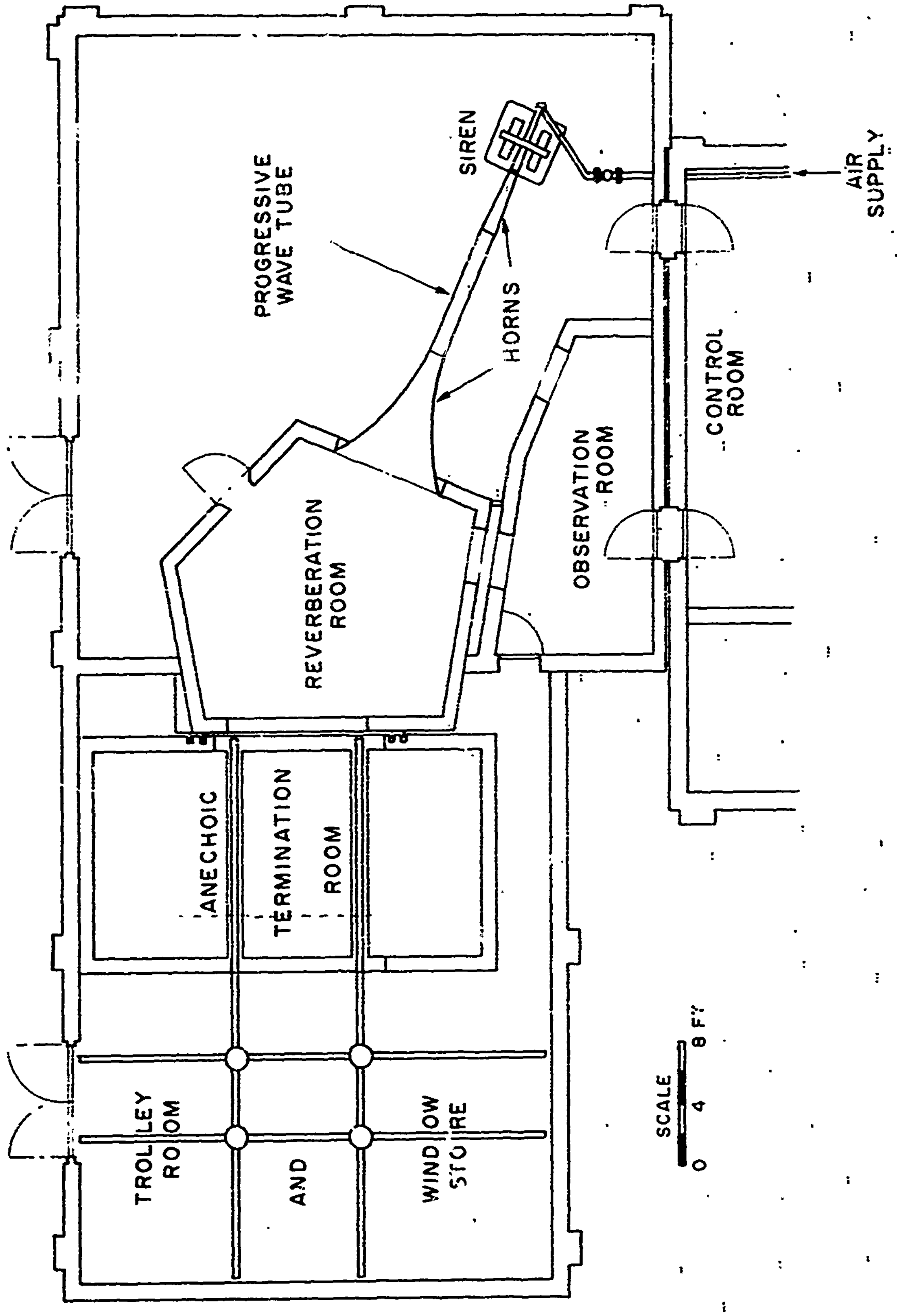

FIG.1: ACOUSTIC TEST FACILITY

these three types of noise must be investigated in greater detail. The systematic development of quieter high speed jets depends on the causes of the noise being understood more fully.

As well, work continues on analytical and experimental studies of the response of aircraft structures to these noise sources[40]. Emphasis has been placed on the development and verification of finite element techniques for response prediction.

CURRENT AND PROPOSED NOISE STUDIES

The jet noise studies have been directed towards the clarification of aspects of high speed jet noise and, as such, complement the well-known jet noise research conducted at the University of Toronto Aerospace Studies under the direction of Prof. H.S. Ribner.

Turbulent Shear Noise

Lighthill's theory can be put in forms that allow the noise of turbulent jets to be computed in terms of the shear flow quantities within the jet. Unfortunately the determination of these flow quantities involves considerable experimental difficulties and is not yet practicable. Recently, a computation method has been developed for turbulent shear layers and this has been successfully applied to a number of aerodynamic problems[30 to 32]. Similar computation techniques which could incorporate information from hot-wire anemometers and fluctuating pressure probes placed within a turbulent jet may be helpful in calculating the strength of the noise sources distributed within a jet.

Shear Wave Instability and Mach Wave Radiation

Theoretical studies of instability waves in laminar or turbulent shear layers indicate large growth rates for subsonically travelling waves and smaller rates for supersonically travelling waves. The theory predicts that the supersonically travelling waves should be the source of an intense directional beam of sound in the form of Mach waves. Optical studies of the inclination of the Mach waves to the main flow of a small high speed jet and measurements of the sound intensity appear to support the predictions of the theoretical models[42,43]. (See Fig. 2a and 2b).

Wave Amplification Due to Sound Wave and Jet Interaction

A theoretical study of the amplification of sound waves in a supersonic flow has been completed and the results published[33]. From schlieren photographs of the sound field of a supersonic jet, it appears that waves may be fed back into the main jet, through the shear layer to the supersonic inviscid core, and subsequently emitted again at the jet boundary. This indicates that one of the mechanisms by which the sound wave can extract energy from the main flow is due to wave amplification through the turbulent shear layer and the inviscid supersonic jet.

Shock Cell Noise

A number of papers on the near field noise of a choked screech jet have been published[21,23,25,28]. A theoretical method of computing the sound field and the

FIG. 2a: "PERIODIC MACH WAVES" FROM A
SUPERSONIC JET

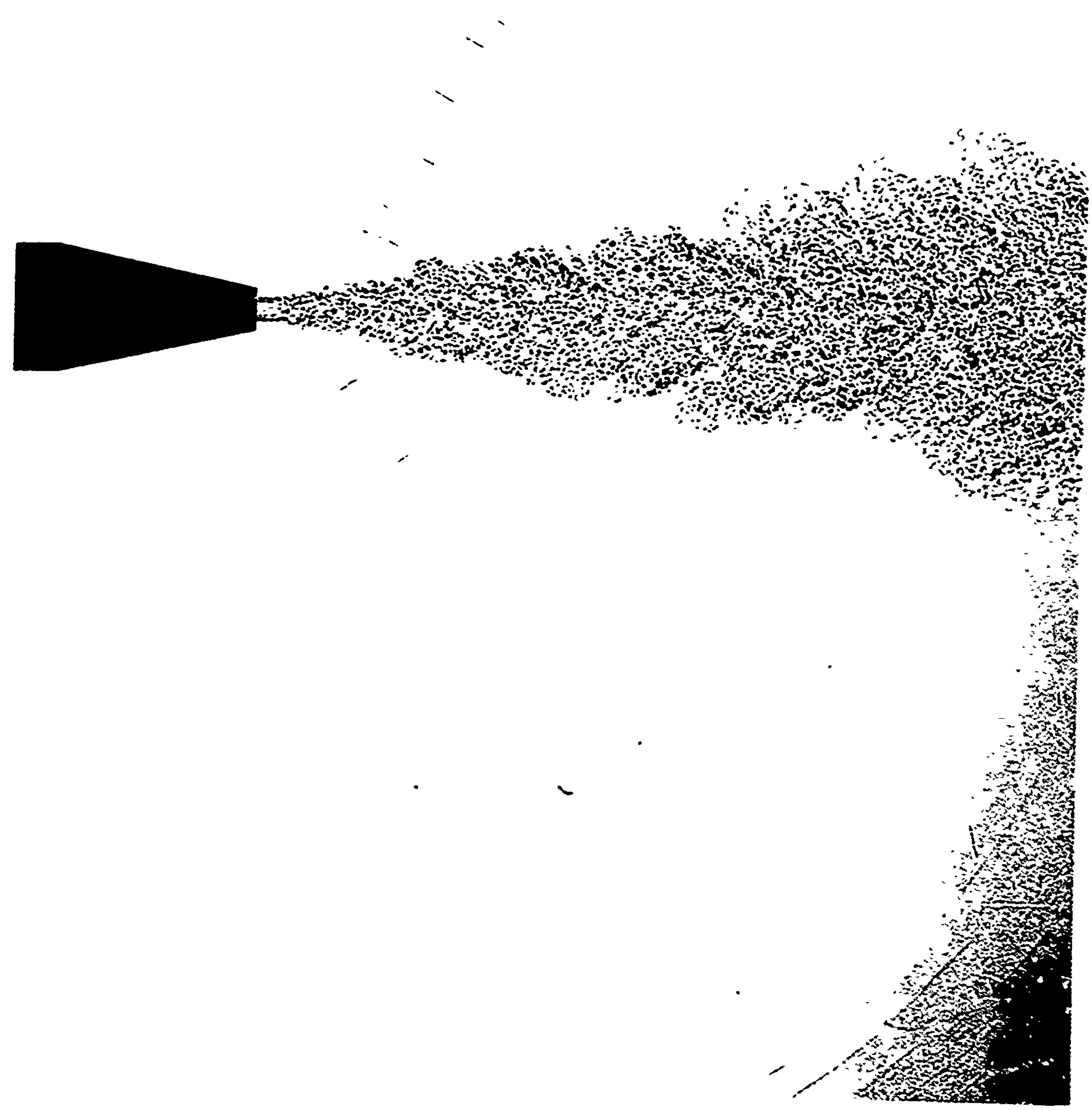

FIG.2b:"PERIODIC MACH WAVES" FROM A SUPERSONIC JET

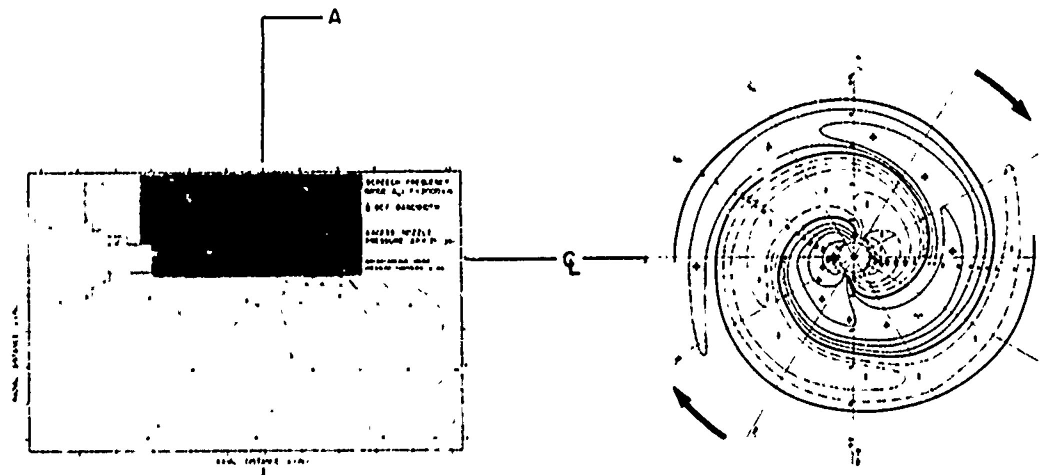

FIG.3: SPINNING SHOCK CELL NOISE

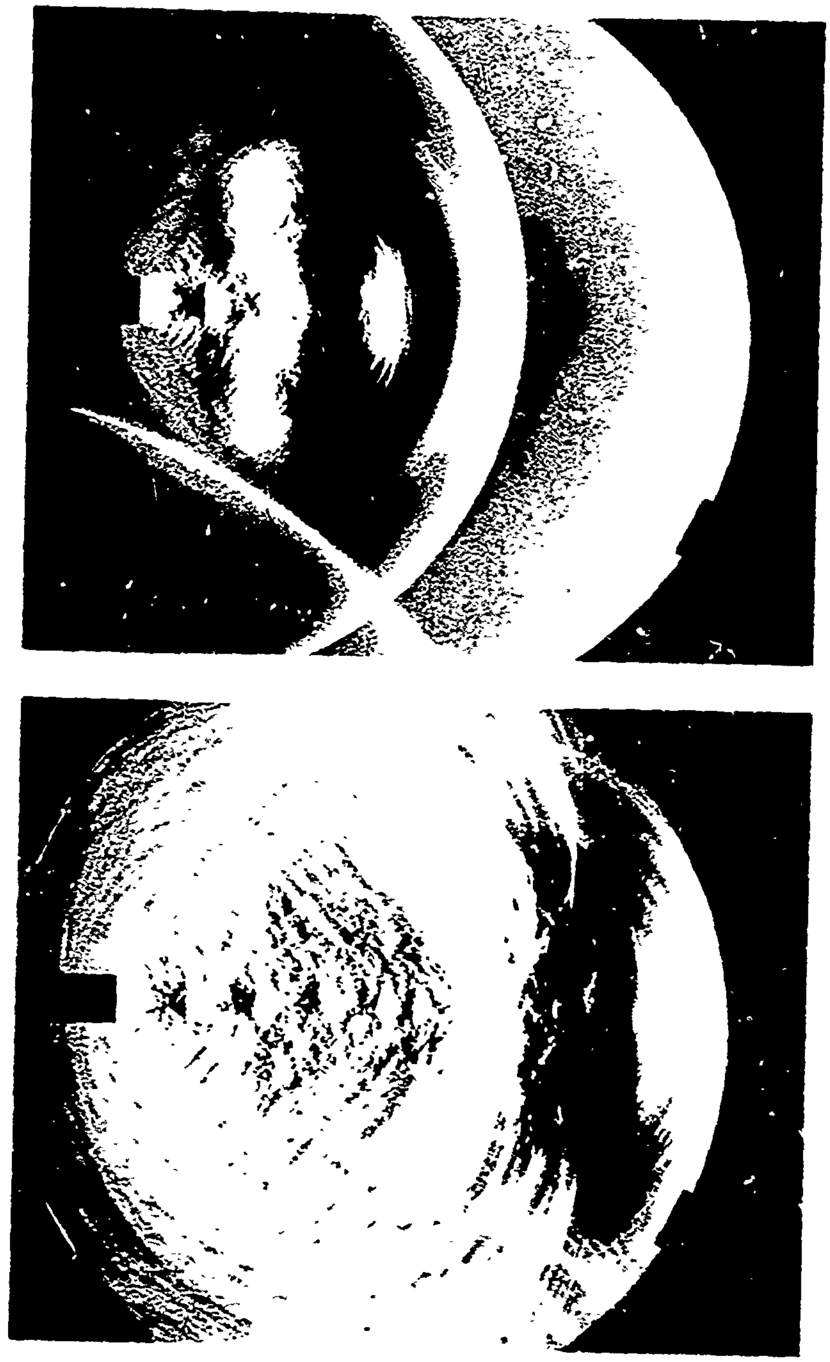

FIG. 4: NOISE RADIATED DURING JET START

location of the effective sources has been completed[34,38]. Future work will be devoted to the formulation of a more sophisticated model and more detailed measurements of the near field under various screech frequencies. Figure 3 illustrates a spinning sound field associated with a screeching jet. Figure 4 illustrates the growth of the sound field when a choked jet starts from rest.

Finite Amplitude Sound Waves

A theoretical consideration of finite amplitude sound waves and the generation of higher harmonics has been completed[35]. For a choked jet, the measured sound pressure levels have been found to be above 170 db near the jet boundary. The linear theory of sound waves are inapplicable in this region and the non-linear theory must be used. This theory will be useful for computing the sound field near the jet boundary. Experimental measurements near the jet will be needed to verify this theory.

Jet Flow in a Moving Medium

A study of the noise produced by a jet in a moving medium using the 5-foot × 5-foot Trisonic Wind Tunnel has been proposed and a preliminary design of a model has been completed. With the mechanisms of the different modes of noise production known from the above-mentioned program, it is possible to distinguish wind tunnel and support interference noise from the jet noise in the experiment. This project will simulate a real jet (although cold) in actual flight and information obtained will be valuable to compare with static model jet test measurements.

Noise Reduction

Methods of noise reduction will be more fully investigated after the mechanisms of the various sources of jet noise are more clearly understood. Experiments on perforated nozzles have yielded very significant changes in the radiated noise[41]. (Compare Fig. 5 for unsilenced nozzle with Fig. 6 for perforated nozzle.)

Wind Tunnel Noise

Extraneous pressure fluctuations in the working section of high speed wind tunnels are not yet fully understood and may restrict tunnel test programs[2,30]. Continuing measurements and monitoring of free stream noise in the NAE 5-foot blowdown tunnel are required. Figure 7 illustrates this phenomenon.

V/STOL Noise

A number of aerodynamic noise problems which are of immediate interest to STOL aircraft are now arising.

The augmentor wing with its choked two-dimensional jet requires investigation of its noise characteristics and also the application of noise suppression techniques. The group's previous experience on choked jet noise provides an excellent background for tackling this problem.

FIG. 5: JET NOISE WITH PLAIN NOZZLE

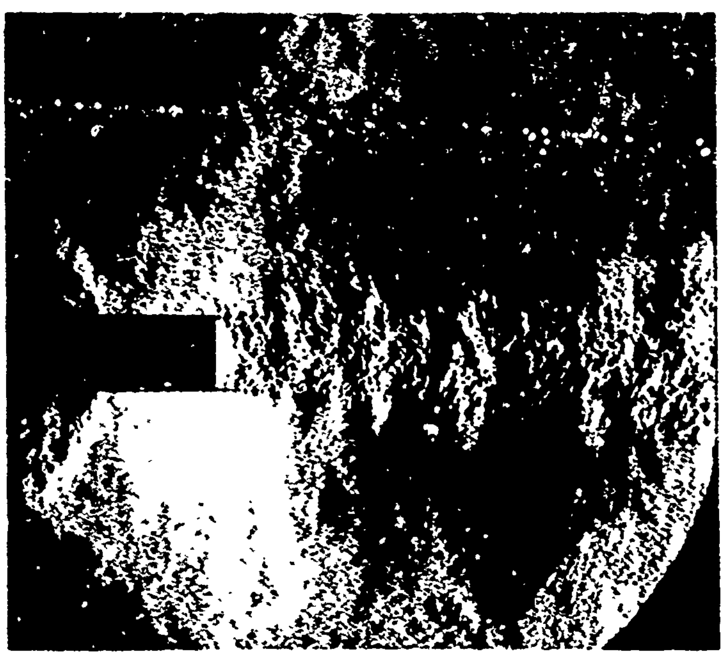

FIG.6: JET NOISE WITH PERFORATED NOZZLE

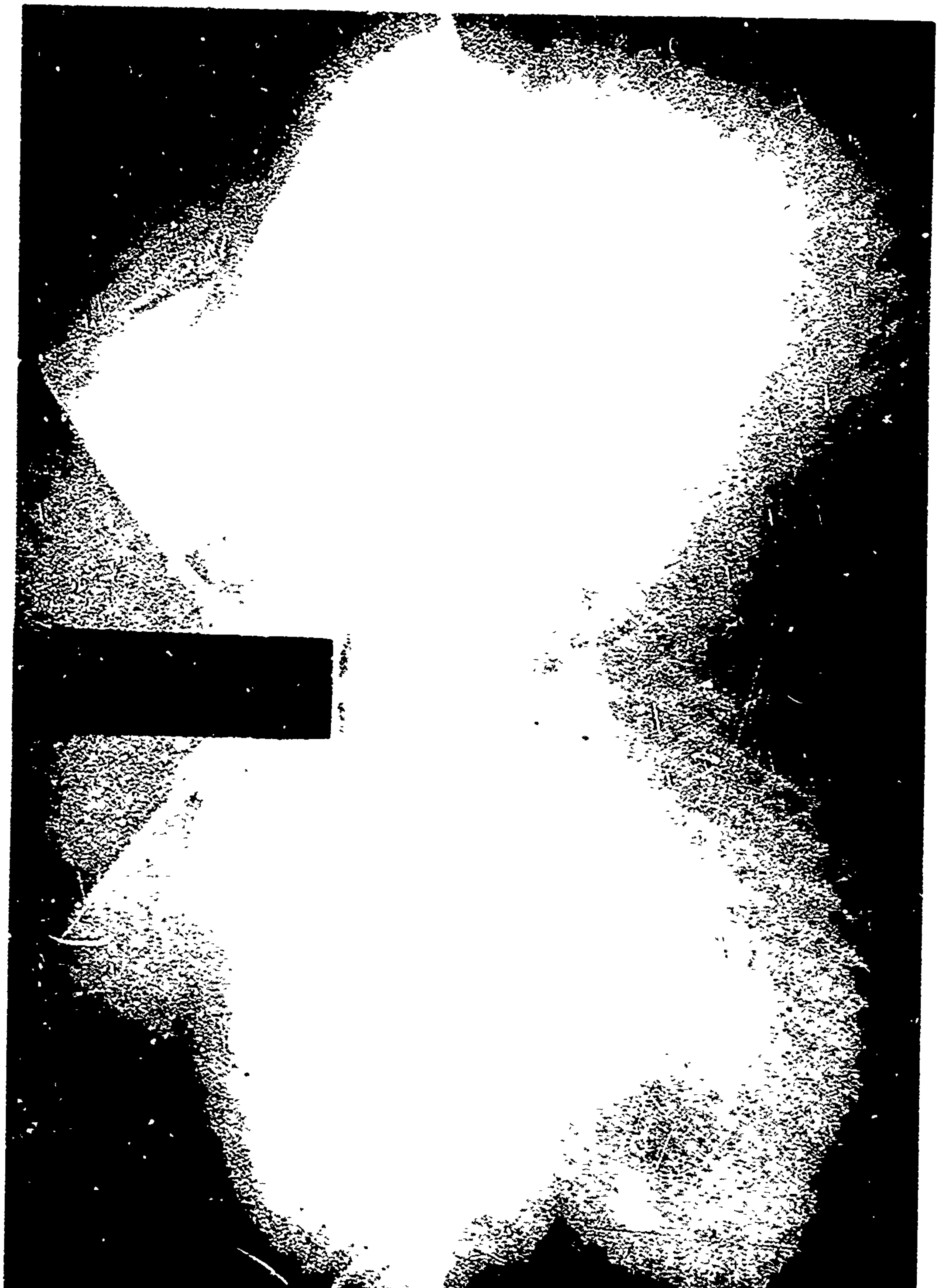

FIG. 7: TRANSONIC WIND TUNNEL NOISE

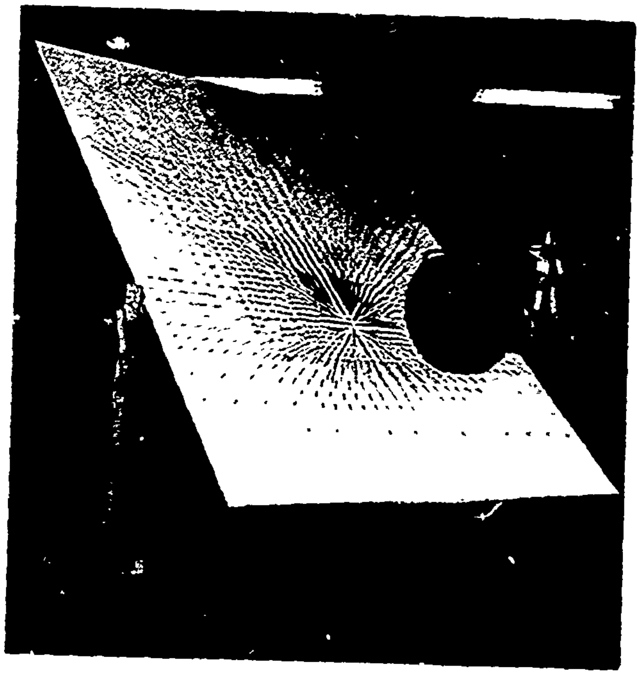

FIG. 8: JET IMPINGEMENT RIG

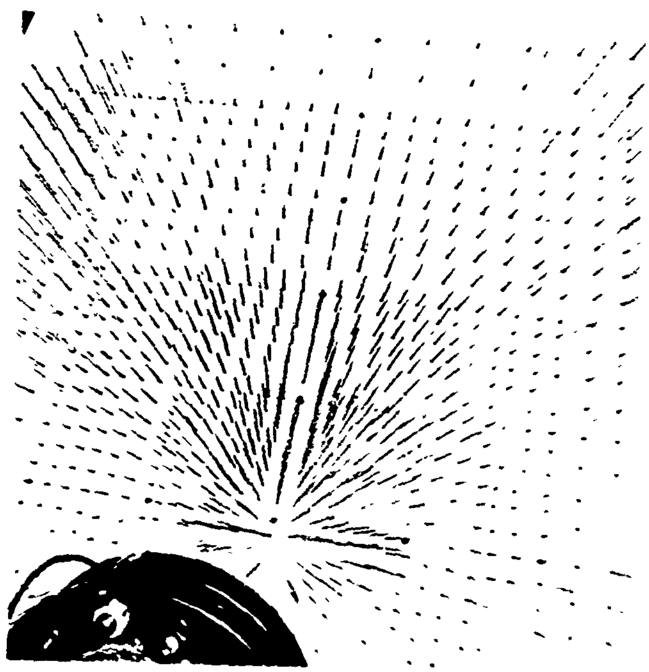

FIG. 9: SURFACE FLOW UNDER IMPINGEMENT

The externally blown jet flap has resulted in a major source of noise radiation and structural excitation at the area of jet impingement. An experiment (see Fig. 8,9) has been started to measure the pressure fluctuations under impinging jets[39].

The reduction of jet engine noise by the design of engines with lower velocity jets has not been as effective as was first hoped because of residual background noises which are transmitted down the jet pipe from within the engine. As well as locating the internal noise sources for each particular engine, it is necessary to determine the manner and direction in which these noises will re-radiate through the external jet. Experiments are under way to clarify some aspects of this type of interaction and unexpected interactions have been discovered between the internal noise and the jet shear layers (see Fig. 10).

The reduction of propeller and rotor noise may depend on the development of high-lift low speed propellers with modified aerofoil sections and plan forms. A four-bladed STOL propeller has already been tested aerodynamically in the 5-foot Trisonic Wind Tunnel and, in the future, it may be advantageous to include the collection of aerodynamic noise data as a supplement to such tests.

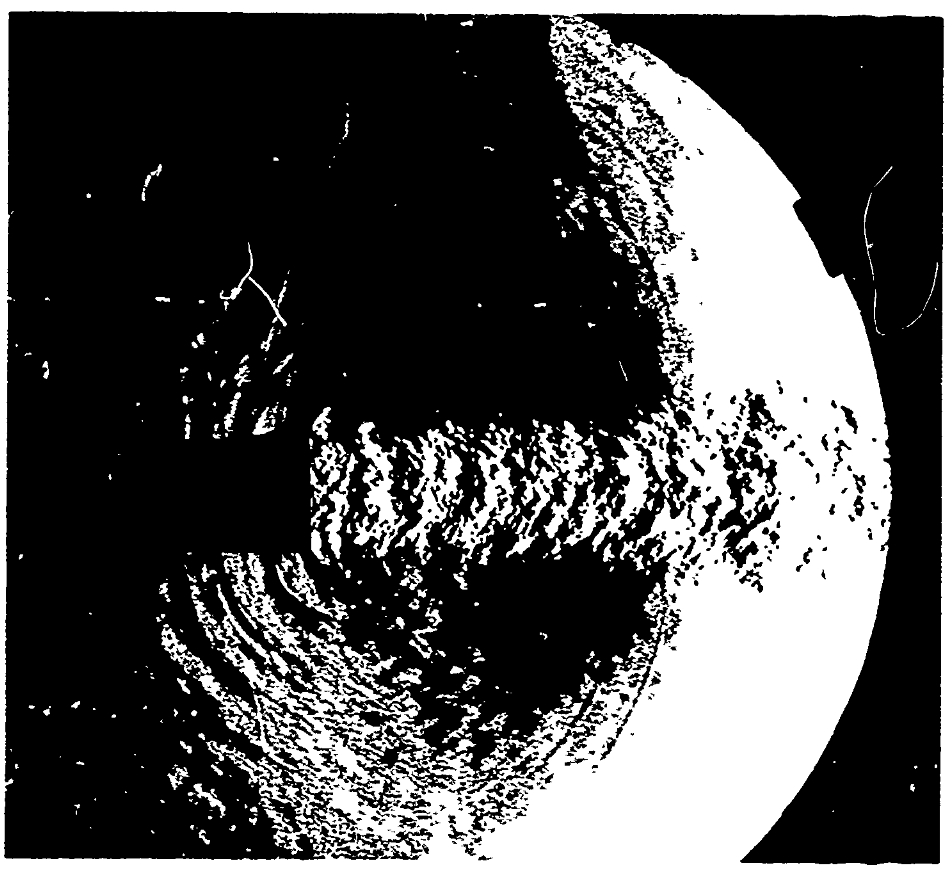

FIG. 10: JET INTERNAL NOISE RE-RADIATION

Trailing Vortices

The slow decay of trailing vortices during the take-off of large aircraft presents a hazard for lighter aircraft. It has been suggested that characteristic noise fields may be associated with trailing vortices and, if so, the presence of vortices could be detected with a microphone. Flight experiments should be carried out to attempt to clarify this possibility.

Jet Noise Fields in Flight

Extremely few measurements have been taken of the near field noise of jets in flight in spite of the important structural response and applications. The Flight Research Laboratory of NAE has the ability to complete near field noise explorations during flight and it may be profitable to fit a microphone to a NAE aircraft.

Atmospheric Transmission of Aircraft Noise

Measurements of the transmission of aircraft noise in the atmosphere have been completed in the USA and UK but equivalent measurements have not been made under the low temperature conditions found in Canada during the winter. It appears that the USA and UK results might be usefully supplemented by experiments completed during the Canadian winter.

Fluidic Controls

Co-operation between the NAE Fluidic Control group and the Aerodynamic Noise group has been productive in solving fluidic control problems and in discovering some fundamental jet noise phenomena. The latter, in turn, may be instrumental in giving a better understanding of shock cell noise on large jets and points a way to its reduction.

The investigation resulted in the discovery of a new form of radiation which we have termed "periodic Mach Wave radiation" (Fig. 2a and 2b). This type of radiation is associated with a non-symmetric spreading of the jet boundary and with very low frequency oscillations.

Stiffened Panel Response to Jet Noise

Recently, a study[27,29,37] was made of the mode shapes and random response of a five-bay integrally stiffened panel in near field jet noise. Mode shapes and response were measured at one position in the noise field and also predicted using finite element techniques (see Fig. 11). Excellent agreement between theory and experiment was obtained. This panel will be located at several other limiting positions in the jet noise field and the experimental response will be measured. The characteristics of the noise field will also be measured. Limited numerical predictions of the response will be made to demonstrate that the finite element techniques developed are applicable to a variety of correlatable noise fields[40].

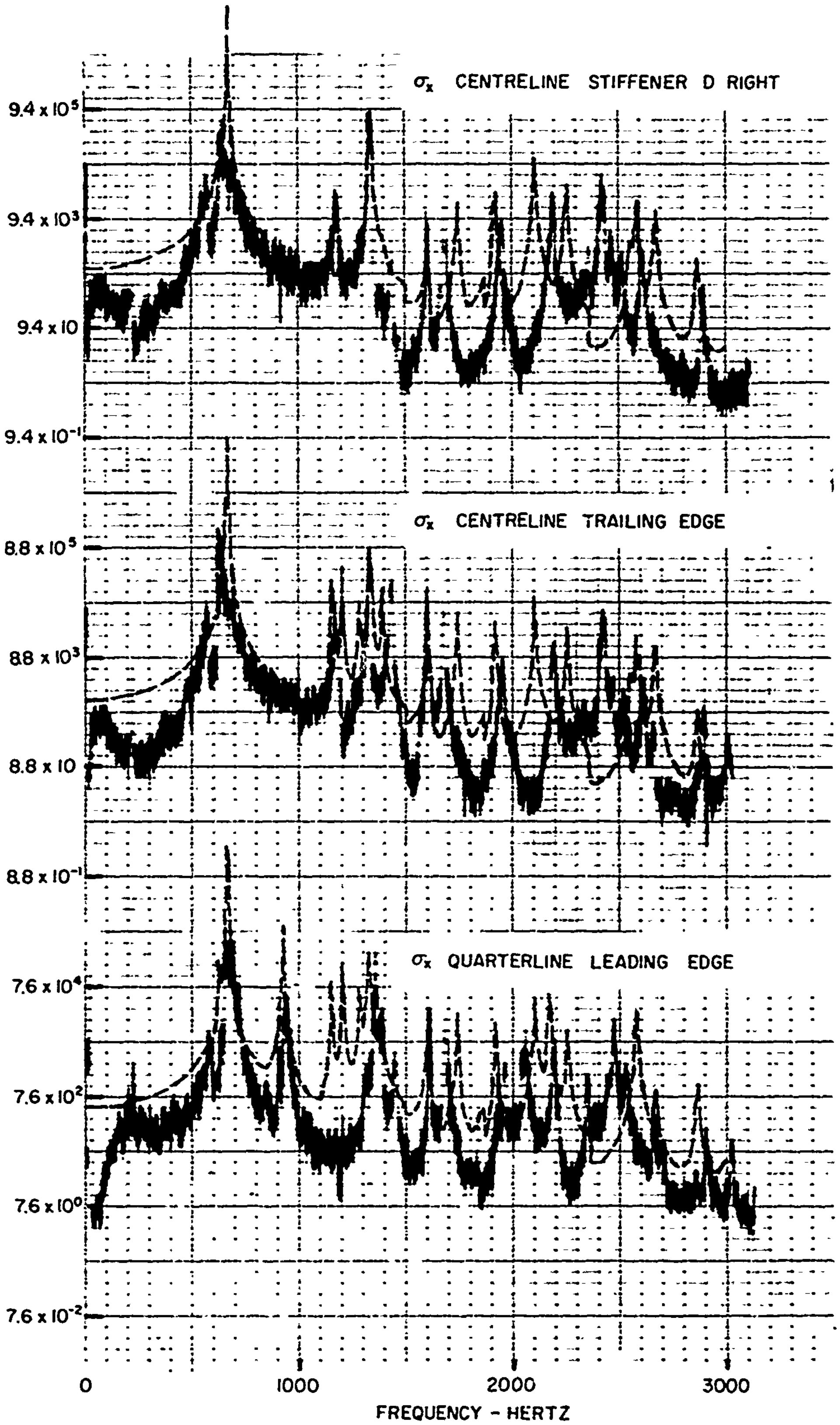

FIG. 11: EXPERIMENTAL AND THEORETICAL SPECTRA OF A FIVE-BAY STIFFENED PANEL

Response of Curved Stiffened Panels

The techniques developed above for flat stiffened panels will be extended to curved panels. The high precision curved finite elements developed at NAE recently will be utilized in this study. Particular attention will be paid to the effects of in-plane stresses on structural response.

Response of Box Structures and Control Surfaces

Many of the current acoustic fatigue problems occur in the relatively lightweight structures used for control surfaces. These complex structures are also amenable to finite element analysis. Such studies will become increasingly important to Canada if the development of blown flap STOL aircraft proceeds.

CONCLUDING REMARKS

Noise research is interrelated with a wide range of unsteady high speed aerodynamic processes and structural problems which are of direct interest to, and under study by, the NAE. There are at least three major areas of applied interest to Canada: the environmental noise problems of CTOL near airports; the development of a quiet STOL aircraft; the area that covers the large variety of aerodynamic noises which are emitted by almost all unsteady high speed flows. The latter is a rich area for fundamental research with many possibilities of spin-off applications in the relatively unapplied field of unsteady aerodynamics.

This article has attempted to define some of these areas, to outline noise research efforts to date and to indicate the probable directions of future research. Clearly, it is not possible (nor desirable) to cover all areas of noise research, but an attempt has been made to include a watching brief on aerodynamic noise aspects which are of direct interest to the National Aeronautical Establishment and to Canada.

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THE DYNAMICS OF CONTAINED OIL SLICKS

D. L. Wilkinson

Hydraulics Laboratory

Division of Mechanical Engineering

INTRODUCTION

People who dirty their hands cleaning up oil spills have a tendency to regard the theoretical ponderings of manicured academics with more than a degree of skepticism. And in this they are largely justified. Numerous papers are written describing devices which solve the problem of oil spill clean-up but which in fact have only been tested in sheltered laboratory flumes or at best in confined and protected waterways.

It is well known that when oil spills onto a water surface it spreads rapidly to form a thin film, eventually only thousandths of an inch thick. At present there is no known means of removing an oil film as such from a water surface other than by the natural processes of evaporation and biological degradation. The efficiency of man devised removal techniques increases rapidly as the thickness of the slick itself increases so that confinement of the slick is usually the first step in the clean-up procedure.

Oil booms, which restrict the movement of oil on the water surface, are commonly used as the confining apparatus. Wind and currents will cause oil to accumulate on the upstream side of any partially submerged barrier which impedes the flow of oil on the water surface. Figure 1 shows an oil slick contained in a flowing stream.

Unfortunately oil slicks cannot always be contained in this way. Wind and waves can splash oil under and over an oil boom which itself may fail structurally due to the drag forces of currents and waves. However these faults are basically design failings and it is foreseeable that in the future they can be rectified to some extent.

But there is another more basic limitation to oil booms and this is dynamic instability of the slick itself over which the boom designer has no control. This instability can occur in any slick contained in water of finite depth and develops when the slick thickness is approximately one third of the flow depth. Fortunately its occurrence can also be predicted when a dimensionless number based on the stream velocity upstream of the slick, the stream depth and the density of the oil attains a critical value.

The criteria for the dynamic stability of an oil slick are examined so that regions of a channel, river or tidal estuary where containment of oil slicks is possible, may be determined in advance. Attempts to contain oil in areas when the slick would be dynamically unstable are bound to fail.

THE FORM AND DYNAMICS OF A CONTAINED OIL SLICK

Contained oil slicks may take one of several forms, depending upon the relative depths of the barrier and the stream, the density of the oil, and the current speed. The oil-water interface may be stable and uniform as in Figure 1, it may be underflowing as in Figure 2 if the barrier is of insufficient depth or it may be turbulent and unstable as in Figure 3.

Interfacial waves are generally visible behind the head of any contained oil slick and these will travel downstream along the interface. The interfacial waves are associated with energy dissipation which occurs in the main stream as it flows beneath the slick.

Energy loss is an essential feature of the flow mechanism and increases significantly as critical conditions are approached. The increase in wave amplitude at this stage is apparent in Figure 3. Oil is swept beneath the barrier as interfacial waves break at the boom and increasing its immersion depth will not prevent this loss. This mode of failure differs from the simple underflow failure shown in Figure 2 which may be prevented by increasing the immersion depth of the barrier.

A contained oil slick obstructs the passage of a stream causing it to accelerate beneath the constriction. In doing so the water exerts a force on the slick compelling it to assume a finite thickness. As might be expected, this dynamic force causes the initial rapid increase in thickness of an oil slick which is clearly visible in Figure 1. It has been found that oil slicks reach their dynamically induced thickness ten to twenty times this thickness downstream from the leading edge, where the flow beneath the slick is again relatively uniform.

Real fluids are never inviscid and hence a stress is transmitted across the shear layer at the oil-water interface. Consequently the magnitude of the shear force acting on the slick increases with distance downstream.

The dynamic force and the shear force are basic in determining the form of a contained oil slick. Wind stress and waves will also affect a slick but will be neglected in the present study which is aimed at determining the criteria for dynamic stability of a slick rather than attempting to define its form in any detail.

As the dynamic and shear forces affect an oil slick in different ways it is appropriate to examine the relative magnitudes of the two forces and determine in what regions of a slick they are important. Consider the schematic in Figure 4. As a first approximation we may treat the slick as a half body in a semi-infinite streaming fluid so that it will experience a force equal to

$$\rho U^2 d$$

where ρ is the density of the water

U is the velocity of flow upstream of the slick

d is the thickness of the slick at the section of interest.

The above is exactly correct for an infinitely deep stream and will overestimate the dynamic force in streams of finite depth.

The viscous force exerted on the slick is obtained by integrating the interfacial shear stress to the section of interest, thus

$$\int_o^x \tau_i \; dx$$

where τ_i is the interfacial shear stress

x is the length parameter measured downstream from the front of the slick.

This equation can be written in terms of a dimensionless friction coefficient C to give

$$\int_o^x \tau_i \; dx = \frac{1}{2} \rho U^2 \int_o^x C \; dx$$

The magnitude of the friction coefficient must be determined experimentally. Cross and Hoult (1971) found it to be approximately constant in value and of the order 10^{-2}. Hence the ratio of dynamic force to viscous force at any section is given by:

$$200 \; \frac{d}{x}$$

and we can see the effects of viscosity are not significant in determining the form of a slick for some distance downstream. Certainly the shape of a slick for the first twenty or so slick thicknesses downstream of the leading edge is almost completely determined by the dynamic forces. The effects of viscosity are simply superimposed onto this basic dynamic form. If we now show that under certain circumstances dynamic effects prevent a stable slick from forming then viscous forces cannot change that situation.

Benjamin (1968) analyzed the problem of an air cavity advancing along the roof of a long container which is sealed at one end. This flow is hydrodynamically similar to a gravity current of salt water advancing into fresh water, or an oil slick contained on the surface of a moving stream. Benjamin's solution is adapted to describe the arrested oil slick in Appendix 1 and results from that analysis are introduced directly into the text of this paper.

A diagram of a stable slick is shown in Figure 4. The frontal thickness of an oil slick can be determined by equating pressure forces acting at sections upstream of and across the slick (sections 0 and 1 respectively) to the change in momentum of the stream between these two sections. As a stagnation point exists in the stream flow at the very front of the slick, (point B in Figure 4), the Bernoulli relation for the surface streamline AB dictates that the elevation of the slick must exceed that of the stream's free surface by an amount equal to the velocity head of the stream. Once this elevation of the slick (ϵ) has been calculated, the pressure forces acting at sections 0 and 1 are readily determined. The momentum pressure force or flow force equation enables the ratio ϕ of the slick thickness to stream depth to be expressed as a function of densimetric Froude number F which describes flow conditions upstream of the slick.

This equation is given by:

$$F^2 = \phi(2-\phi) \left[\frac{2\phi}{1-\phi} + \frac{1}{1-\Delta}\right]^{-1}$$

where the densimetric Froude number is defined as

$$F = \frac{U}{(\Delta g D)^{1/2}}$$

$$\Delta = \frac{\rho_{water} - \rho_{oil}}{\rho_{water}}$$

and

$$\phi = \frac{d}{D}$$

where D = the stream depth upstream of the slick.

It is important to note that F (henceforth referred to as the Froude number) depends only upon conditions upstream of the slick and the specific gravity of the oil. Hence for a river of known cross-section and discharge, Froude numbers can readily be calculated for oils of any given density. It will be shown that the stability of an oil slick depends only upon the value of the Froude number at the particular section of interest. Knowledge of this basic parameter enables one to determine whether containment is possible at a particular section, and if so, the depth to which a barrier must be immersed if that oil is to be contained.

A graph of the flow force equation which describes the equilibrium conditions of a stable slick, is shown in Figure 5 for the special case of $\Delta = 0.00$. (The corresponding curve for $\Delta = 0.20$, as well as $\Delta = 0.00$ covering the range of Δ likely to be met in prototype slicks is shown in Figure 8. It can be seen Δ has only a small effect on the form of the relationship between F and ϕ.) The particular case of $\Delta = 0.00$ will be discussed but the characteristics of the F - ϕ relationship are general.

It can be seen in Figure 5 that two values of slick thickness satisfy the flow force equation for any Froude number less than 0.53, and that no solutions exist when the Froude number exceeds this value. This latter statement implies that a stable slick does not exist at Froude numbers which exceed the critical value of 0.53. Experiments support this conclusion and containment of a slick at Froude numbers above 0.53 indeed proves impossible. Figure 3 shows the appearance of an oil slick at Froude numbers of 0.55 where the interface has become extremely aggitated and oil is passing beneath the barrier. Increasing the barrier depth at this stage does not prevent oil being sucked down under the boom.

It is worthwhile to examine the rate of energy dissipation occurring in the flow passing beneath the slick. The flow force equation has defined conditions downstream of the frontal zone of an oil slick in terms of conditions upstream of the slick

and consequently any head loss incurred by the flow between these sections is also defined. In Appendix 2 the head loss, H_L, experienced by the flow is expressed as a function of the slick thickness ratio ϕ and the flow depth which for the particular case $\Delta = 0.00$ gives

$$\frac{H_L}{\Delta D} = \frac{\phi(1 - 2\phi)}{2(1 - \phi^2)}$$

Again the head loss is relatively insensitive to Δ. It is apparent from the above equation that meaningful solutions do not exist when ϕ is greater than 1/2 as H_L would then become negative. Consequently the higher values of ϕ associated with Froude numbers of less than 0.53 do not represent physical solutions.

Further information on slick behaviour can be deduced from the relationship between the head loss and Froude number which is plotted in Figure 6. The graph was obtained by simultaneous numerical solution of the flow force and head loss equations. There is a rapid increase in the head loss at Froude numbers above 0.4 and as the Froude number approaches 0.53 the head loss increases extremely rapidly. Since the energy is dissipated as turbulence and in generation of internal waves near the front of the slick, we could expect to see a marked increase in interfacial disturbance as the Froude number approaches its critical value. Experiments confirmed that this was correct and could in some cases lead to the formation of an oil-water emulsion at the interface.

Energy considerations prevent the slick thickness ever exceeding one half the stream depth and therefore the region OA of the curve in Figure 5 is of no practical interest. It is interesting to consider whether the larger ϕ values associated with Froude number between 0.5 and 0.53 represent physically attainable states. In any real oil spill the initial spread is extremely rapid so that the slick thickness on first reaching a boom is certainly less than the equilibrium thickness given by the flow force equation. The slick thickness will increase from an initially small value as more oil accumulates and hence ϕ will similarly increase to a final steady value, assuming one exists. It can be shown that the smaller slick thickness is stable for small perturbations in the layer thickness and since in practice this lower valued solution will always be reached first, it is difficult to imagine the larger ϕ values ever being realized.

We may conclude that oil slicks having ϕ values greater than 1/3 will very probably not exist.

EXPERIMENTS

Experiments were conducted to test the predictions of the foregoing discussion and in particular to examine the behaviour of contained oil slicks at supercritical Froude numbers.

The experiments were performed in a glass-walled flume of cross-section 15 inches wide by 15 inches deep. A diagram of the experimental flume is shown in Figure 7. The modified working section of the flume comprised a contracted section 3 inches wide and 7-1/2 feet long. An adjustable undershot weir, which acted as the slick barrier, was installed at the downstream end of the working section. Thereafter

the channel expanded again to the full 15-inch width and another undershot weir retained any oil passing beneath the first barrier. An overshot weir at the end of the flume regulated the water levels and inflow to the flume was from a head tank via a control valve. Honeycomb flow straightness at the upstream end of the flume reduced turbulence to low levels. The flow in the working section of the flume was steady and uniform during experiments and velocities were measured by timing dye traces over a distance of three feet in the working section.

Hot water, kerosene and peanut oil were used to simulate the slick in the different experiments. Dyed hot water was used in the preliminary experiments for ease of clean-up. Peanut oil which remains in discrete globules on the water surface and does not wet glass as readily as some other oils was used in the main experimental program. The viscosity of peanut oil is very high, - almost 60 times that of water, and it was thought that the rapid damping of interfacial waves in peanut oil slicks might influence the mechanism of energy dissipation. Kerosene, having a viscosity of only twice that of water was used to examine the dissipation process in slicks of low viscosity.

The results of experiments designed to establish the form of the relationship between the slick thickness ratio ϕ and the Froude number are plotted in Figure 8. The slick thickness (d) was measured approximately 15 to 20 d behind the front of the slick. Interfacial slopes in this region were found to be from 0.001 to 0.005 justifying the uniform flow assumption made in the analysis. Agreement with the theory was satisfactory. Experiments were performed with Froude numbers as high as 0.6, and as expected, the degree of interfacial disturbance increased considerably for Froude numbers in excess of 0.4. Figure 1 shows the form of a slick at a Froude number 0.37 and it can be seen that the interfacial disturbances are relatively slight. Figure 3 shows the slick after the flow velocity had been increased to give a Froude number of 0.55. Large disturbances are plainly visible on the interface and oil was being intermittently swept beneath the barrier. This oil can be seen accumulating in the separation zone downstream of the barrier. At Froude numbers in excess of approximately 0.55 it was found that oil loss could not be prevented regardless of the barrier depth. Any increase in depth was counteracted by the increase in the velocity field of the flow beneath the barrier.

The onset of interfacial turbulence at near critical Froude numbers was most apparent in the kerosene slicks. At Froude numbers in excess of approximately 0.4, the turbulence caused a kerosene-water emulsion to form at the interface and in practice this would further restrict the range of Froude numbers for which containment is feasible. Interfacial turbulence was inhibited when the viscosity of the slick was high.

The hot water slicks behaved similarly to peanut oil slicks for Froude numbers of less than 0.4. Above this value the increased energy dissipation caused mixing at the interface which became ill-defined.

CONCLUSIONS

It has been shown that there is an upper limit to the Froude number for which oil slicks may be contained in any river or estuary. Theoretically this limit is reached at a Froude number of 0.53 for oil with a specific gravity of 1 (and 0.49 for oil with a specific gravity of 0.8) but experiments have shown that increased interfacial turbulence makes containment impractical at Froude numbers greater than 0.4.

Studies of the St. Lawrence River indicated that containment of oil slicks in this river will prove extremely difficult for large proportions of the tidal cycle in the areas downstream from Quebec City and Montreal (Wilkinson, 1971).

It will be noted that the thickness of oil slicks can be calculated from the theory contained in this paper. It must be emphasized however that viscous forces were neglected in the analysis rendering it valid for only the frontal region of an oil slick. In oil slicks of any great length (more than 20 times as long as they are thick) viscous forces must be taken into account. The study of Cross and Hoult (1971) will be useful in this regard.

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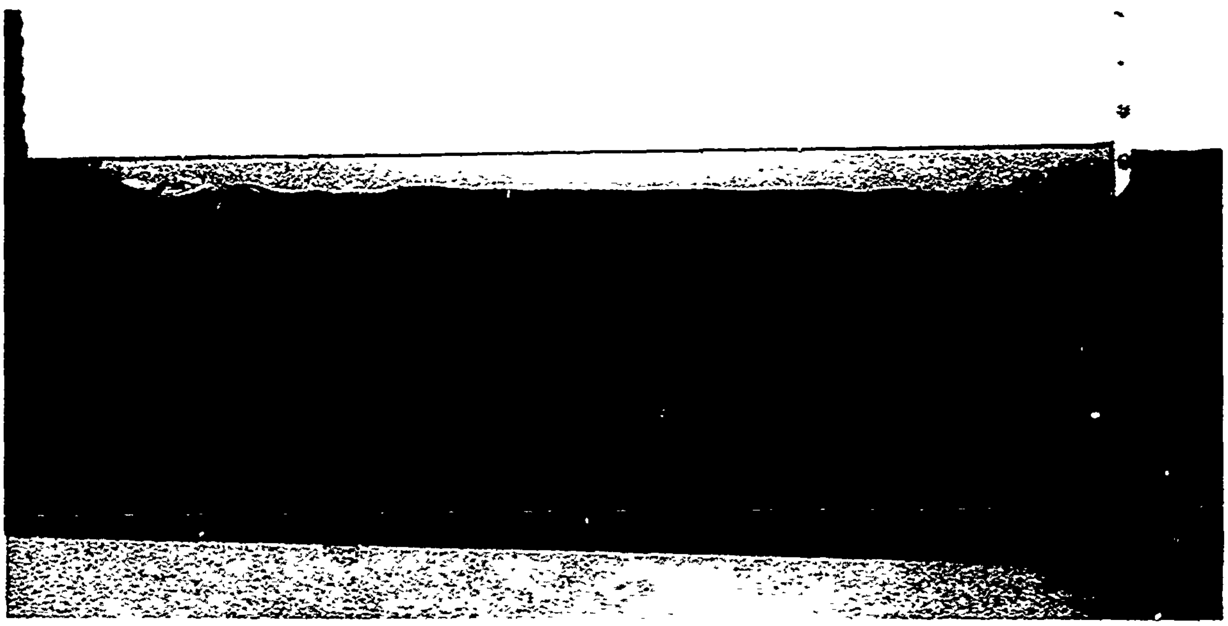

FIG. I: AN OIL SLICK CONTAINED BY A SURFACE BARRIER. FLOW IS FROM LEFT TO RIGHT BENEATH THE SLICK (F=0·37)

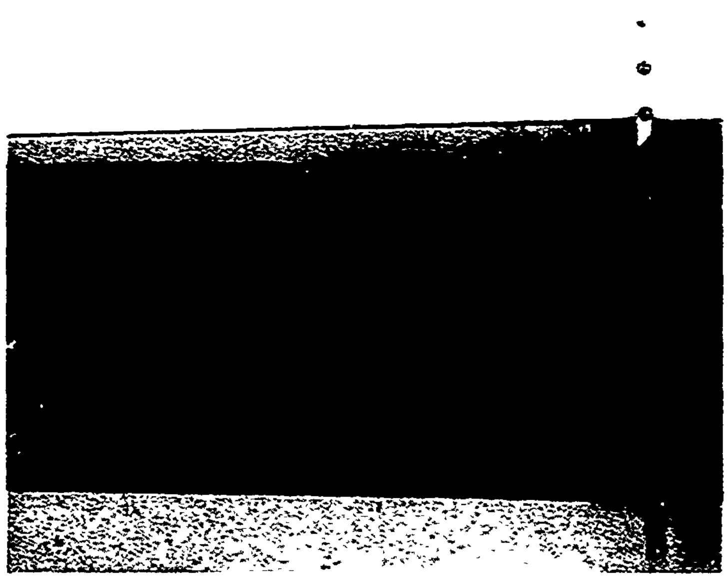

FIG. 2: OIL ESCAPING BENEATH A BARRIER OF INSUFFICIENT DEPTH (F=0·37)

FIG.3: AN OIL SLICK WITH UNSTABLE INTERFACE (F=0·55)

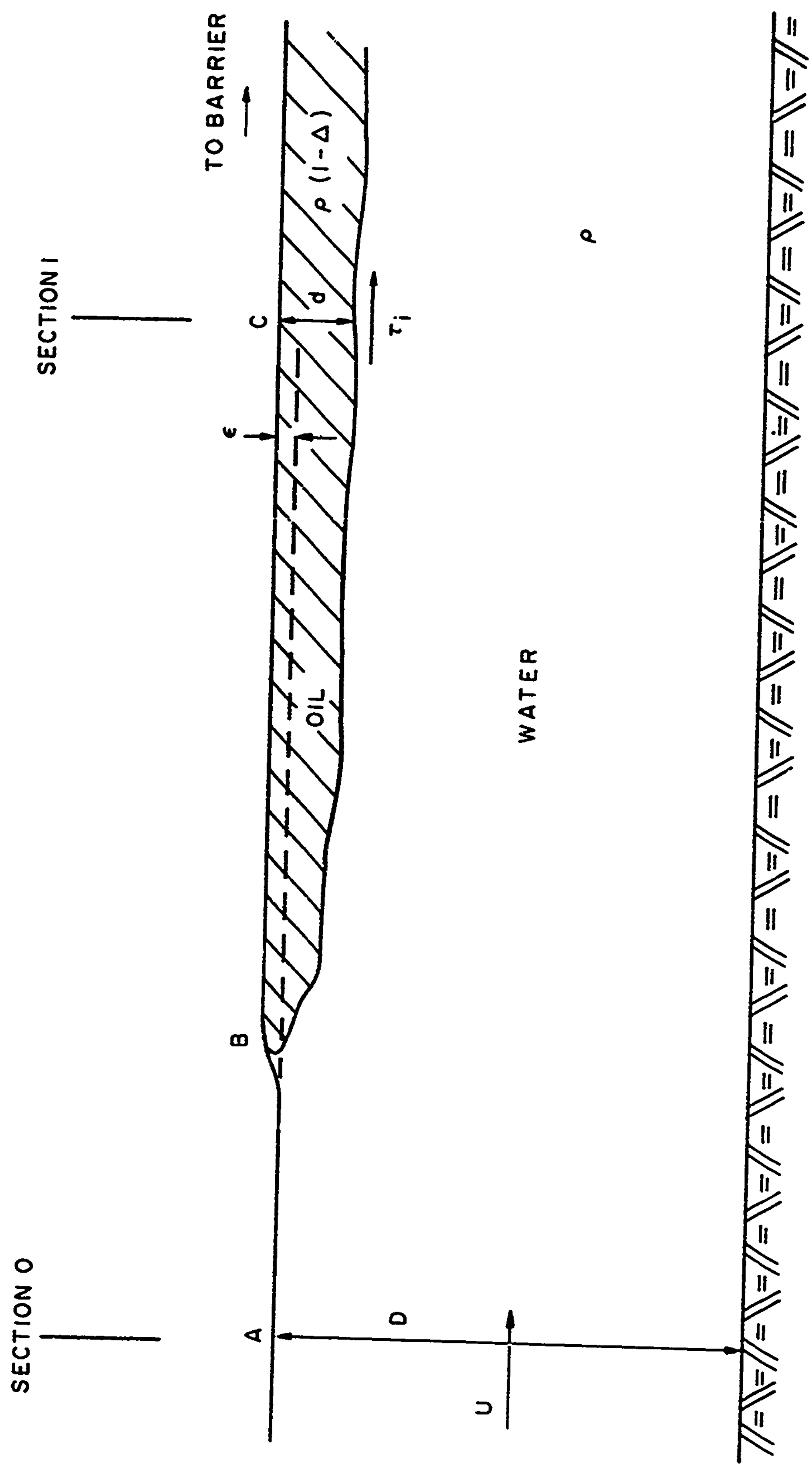

FIG. 4: THE FRONTAL ZONE OF A CONTAINED OIL SLICK

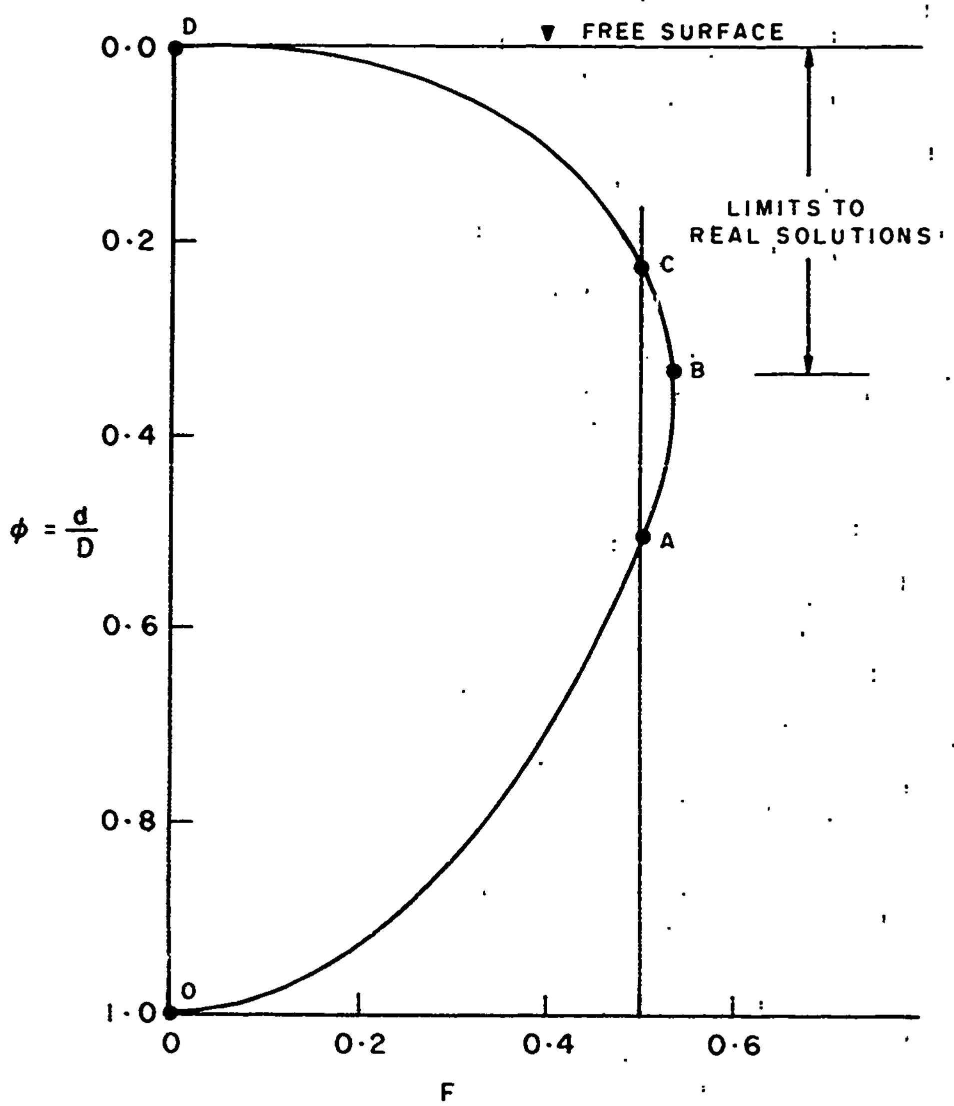

FIG. 5: SLICK THICKNESS RATIO AS A FUNCTION OF FROUDE NUMBER

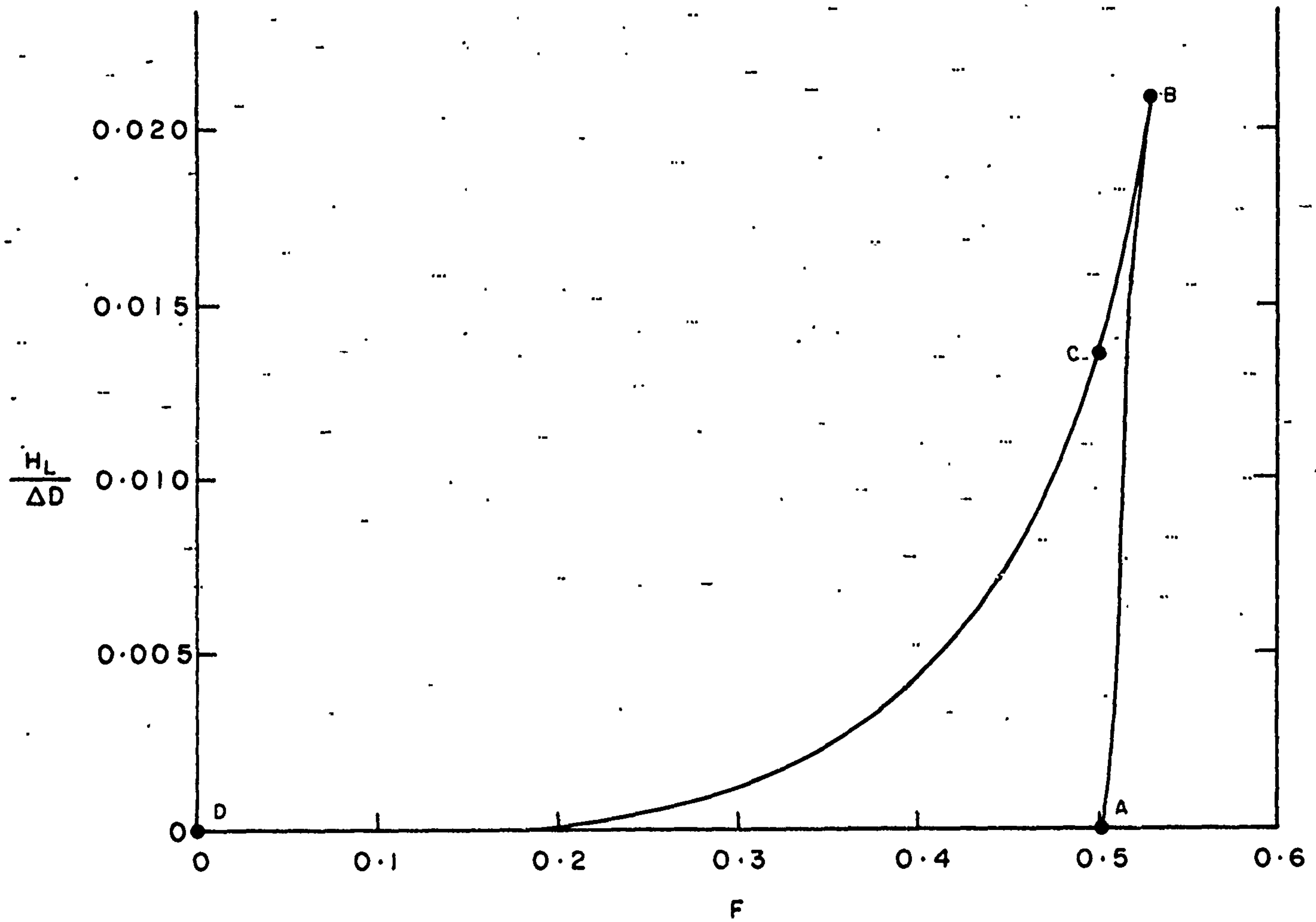

FIG. 6: HEAD LOSS VERSUS FROUDE NUMBER FOR FLOW UNDER AN OIL SLICK

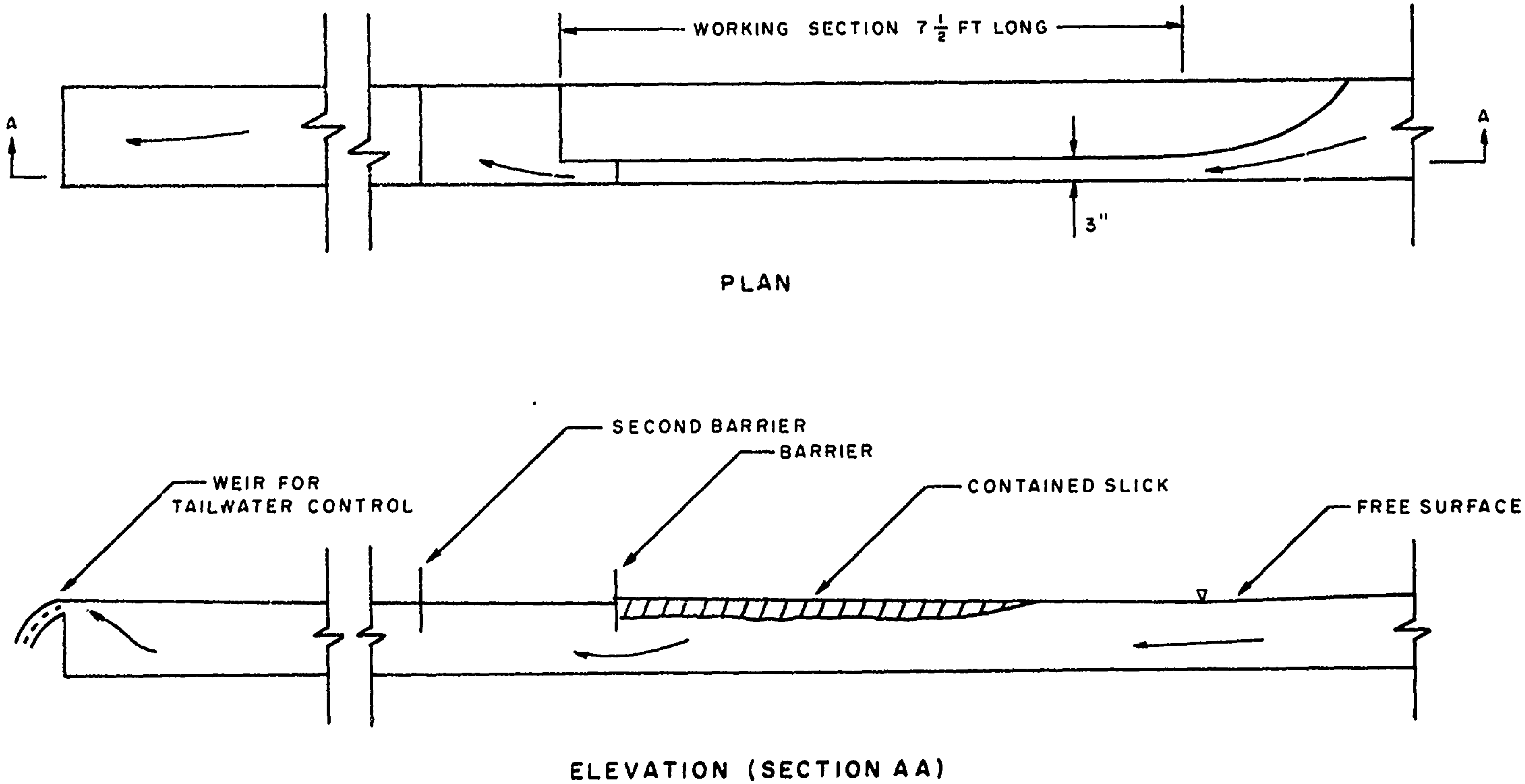

FIG. 7: SCHEMATIC DIAGRAM OF TEST FLUME

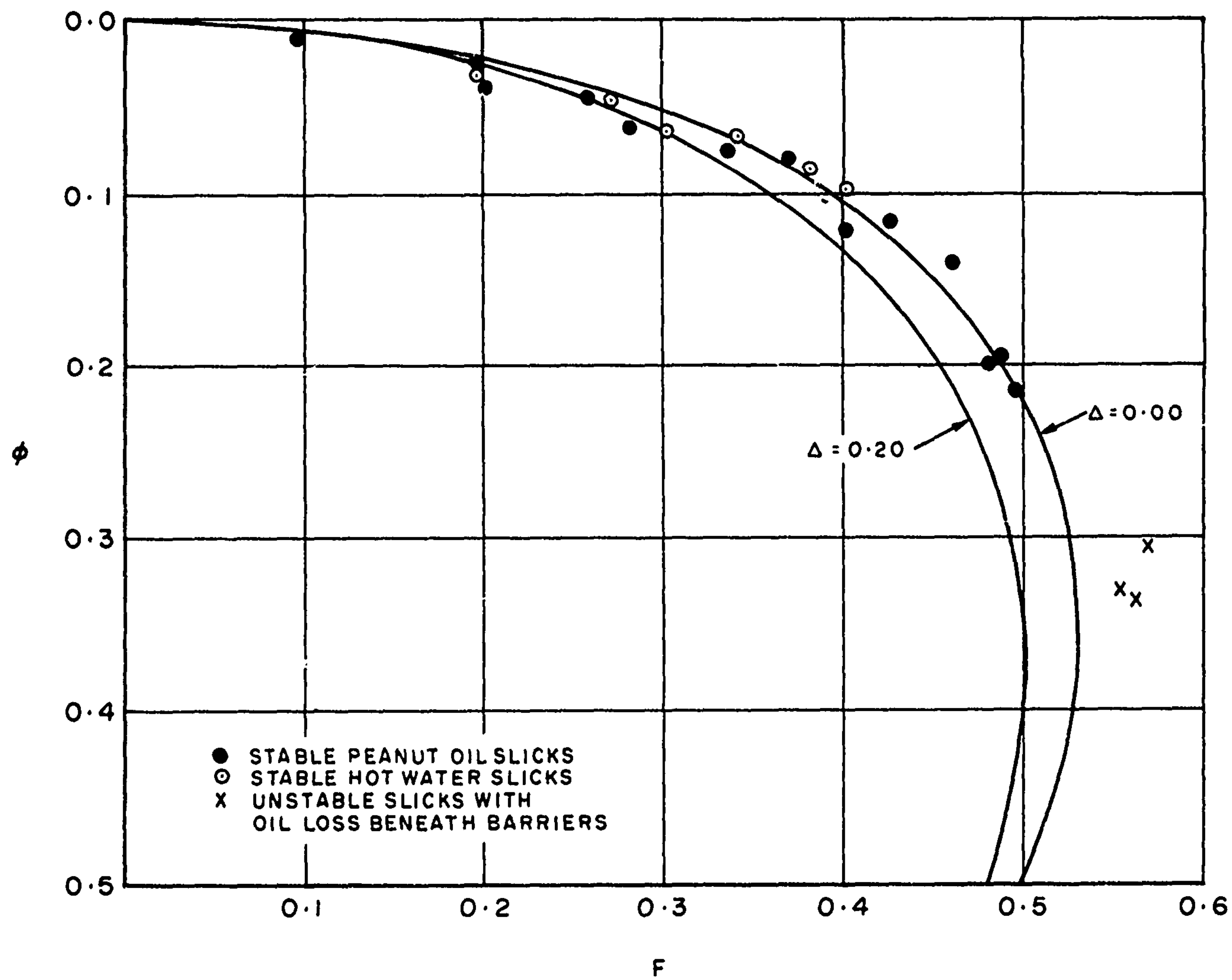

FIG. 8: FRONTAL THICKNESS RATIO AS A FUNCTION OF FROUDE NUMBER

APPENDIX 1

ANALYSIS OF A CONTAINED OIL SLICK

An expression is derived which relates flow conditions in a two-dimensional channel of finite depth, to the equilibrium thickness of an oil slick which can be contained on the water surface in the channel. The flow beneath the oil slick is assumed to be inviscid.

Consider the contained oil slick shown in Figure 4. If one assumes steady uniform flow conditions exist at sections 0 and 1 then the sums of horizontal momentum and pressure force per unit width will be equal at both sections and are given by:

$$\rho U^2 D + \frac{\rho g D^2}{2} = \frac{\rho U^2 D^2}{D+\epsilon-d} + \frac{\rho(1-\Delta)g(D+\epsilon)^2}{2} + \frac{\Delta\rho g(D+\epsilon-d)^2}{2}$$

where
- U = velocity of flow upstream of the slick
- ρ = density of the water
- D = depth upstream of the slick (section 0)
- g = gravitational acceleration
- $\rho(1-\Delta)$ = density of the oil
- d = thickness of the slick

and ϵ = difference in elevations of the free surface at sections 0 and 1.

In any real problem $\Delta\rho$ is small compared with ρ, and ϵ is very small compared with D. Consequently pressure force terms involving $\Delta\rho\epsilon$ and ϵ^2 and momentum terms having ϵ as a numerator will be neglected in the expansion of the flow force equation above. The flow force equation then reduces to the simpler form:

$$\rho U^2 D + \frac{\rho g D^2}{2} = \frac{\rho U^2 D^2}{D-d} + \frac{\rho g D^2}{2} + \rho g D\epsilon - \Delta\rho g D d + \frac{\Delta\rho g d}{2}$$

The difference in levels of the free surface at sections 0 and 1 can be obtained by considering the pressure at the stagnation point B on the streamline AB. As there is no energy dissipation between points A and B, the pressure (p) at B is given by the Bernoulli relationship

$$p = \frac{\rho U^2}{2}$$

This pressure is balanced by an elevation in the surface level of the oil slick.

$$p = \rho(1-\Delta)g\epsilon$$

and therefore

$$\epsilon = \frac{1}{1-\Delta}\,\frac{U^2}{2g}$$

The above equation can now be combined with the earlier flow force expression and non-dimensionalized to give

$$F^2 = \frac{F^2}{1-\phi} + \frac{1}{1-\Delta}\ \frac{F^2}{2} - \phi + \frac{\phi^2}{2}$$

and re-arranging we get

$$F^2 = \phi(2-\phi)\ \left[\frac{2\phi}{1-\phi} + \frac{1}{1-\Delta}\right]^{-1}$$

where $$F = \frac{U}{(\Delta g D)^{1/2}}$$

and $$\phi = \frac{d}{D}$$

The flow force equation above relates the equilibrium thickness of a contained oil slick from conditions upstream of the slick.

APPENDIX 2

ENERGY DISSIPATION ASSOCIATED WITH AN OIL SLICK

The head loss (H_l) incurred by a stream passing beneath a contained oil slick can be determined by comparing values of the Bernoulli constant along the bottom streamline, at sections 0 and 1 in Figure 4. Hence

$$H_l = \frac{U^2}{2g} + D - \frac{U^2 D^2}{2g(D-d)^2} - (D + \epsilon) + \Delta d$$

and it was shown previously that

$$\epsilon = \frac{1}{1-\Delta} \frac{U^2}{2g}$$

which on substituting into the expression for H_l gives

$$H_l = \frac{\Delta}{1-\Delta} \frac{U^2}{2g} - \frac{U^2}{2g} \cdot \frac{1}{(1-\phi)^2} + \Delta d$$

Generally $\frac{\Delta}{1-\Delta}$ will be much less than $\frac{1}{(1-\phi)^2}$ and the first term on the right hand side of the above equation will be neglected in the following analysis. The head loss may be non-dimensionalized by dividing by ΔD to give

$$\frac{H_l}{\Delta D} = \frac{-F^2}{2(1-\phi)^2} + \phi$$

F^2 can be eliminated in the above using the flow force equation. The dimensionless head loss of a stream flowing under a contained oil slick is given by:

$$\frac{H_l}{\Delta D} = \frac{\phi^2(1-2\phi)}{2(1-\phi^2)}$$

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APPENDIX 3

NOTATION

D = depth of flow upstream of the oil slick (ft)

d = frontal thickness of an oil slick (ft)

F = densimetric Froude number

g = gravitational acceleration (ft/sec^2)

H_L = head loss between sections 0 and 1 (ft)

U = velocity of flow upstream of the oil slick (ft/sec)

ϵ = difference in surface levels of the slick and the flow upstream of the slick (ft)

$\Delta = \dfrac{\rho_{water} - \rho_{oil}}{\rho_{water}}$

ρ = density of the water (slugs/ft^3)

ϕ = the ratio $\dfrac{d}{D}$

CURRENT PROJECTS

Much of the work in progress in the laboratories of the National Aeronautical Establishment and the Division of Mechanical Engineering includes calibrations, routine analyses and the testing of proprietary products; in addition, a substantial volume of the work is devoted to applied research or investigations carried out under contract and on behalf of private industrial companies.

None of this work is reported in the following pages.

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ANALYSIS LABORATORY

AVAILABLE FACILITIES

This laboratory has analysis and simulation facilities available on an open-shop basis. Enquiries are especially encouraged for projects that may utilize the facilities in a novel and/or particularly effective manner. Such projects are given priority and are fully supported with assistance from laboratory personnel. The facilities are especially suited to system design studies and scientific data processing. Information is available upon request.

EQUIPMENT

1. An Electronic Associates 690 HYBRID COMPUTER consisting of the following:

   (a) EAI 640 digital computer

   - 16K memory
   - card reader
   - high speed printer
   - disc
   - digital plotter

   (b) EAI 680 analogue computer

   - 120 amplifiers
   - non-linear elements
   - x-y pen recorders
   - 6-channel strip chart recorder
   - large screen oscilloscope

   (c) EAI 693 interface

   - 18 digital-to-analogue converters
   - 32 analogue-to-digital converters
   - interrupts, sense lines, control lines

2. Hewlett Packard Model 3960 FM instrumentation tape recorder. IRIG standard, 4-track, 1/4-inch tape. Speeds: 15/16, 3-3/4 and 15 inches per second.

GENERAL STUDIES

Development of statistical analysis techniques for the analysis of analogue recorded data, including digital and hybrid implementations.

Study of the numerical solution of partial differential equations.

A study is being made on the analogue computer of the differences between the observable and controllable implementations of a model of a PID controller.

APPLICATIONS STUDIES

In collaboration with the Chemical Control Institute programs are being developed for the analysis of turbulence above and below the plant canopy.

A study of an optimal control for a natural gas pumping station.

In collaboration with Queen's University and the University of Bath, a study of the matching problem of turbochargers to reciprocating engines is being made.

Design of a steam power plant for improved transient response and reliability, using a hybrid computer simulation.

In collaboration with H. Julinct/Technology, a linear electric generator based on the free piston concept is being studied on the hybrid computer.

In collaboration with the Control Systems Laboratory and Noranda Mines Ltd. models of converter isle operations are being developed in order to improve crane scheduling and plant performance.

APPLICATIONS STUDIES BY OTHERS

The Communications Research Center is using the hybrid computer to design the altitude control system of a synchronous satellite.

The Department of National Defence is using the hybrid computer for a study of the propulsion system on the DDH280 Navy destroyer. Ship manoeuvre studies are now being conducted.

The Engine Laboratory is using the hybrid computer to design a cam-driven hydraulic pump; the cam being connected to the piston of a free piston engine.

Graham F. Crate Ltd. and Ontario Hydro are using the hybrid computer to test the control algorithms of the Pickering Nuclear Power Station digital control system.

Graham F. Crate Ltd. and Trans Canada Pipelines are using the hybrid computer to study control algorithms for natural gas pumping stations.

The Engine Laboratory is using the hybrid computer to study the gas dynamics of a new configuration for a centrifugal compressor.

McGill University are using the analogue computer to study the dynamic behaviour of phase lock loops.

CONTROL SYSTEMS LABORATORY

INDUSTRIAL CONTROL PROBLEMS

Investigation of industrial systems applications of fluidic circuits.

Investigation of the process dynamics and control characteristics of a copper converter.

Engineering support to specific firms for the implementation of schemes for control and mechanization.

HUMAN FACTORS ENGINEERING

Investigation of the control characteristics of the human operator and the basic phenomena underlying tracking performance.

Investigation of the nature of sensory interaction in human perceptual-motor performance.

Investigation of the factors involved in the presentation and processing of information, particularly in relation to simulator design.

BIOLOGICAL ENGINEERING

Investigation of the implementation of feedback control in living organisms.

Investigation of auditory methods of monitoring electrophysiological signals in general and the electroencephalograph in particular.

Development of techniques for preserving biological specimens including tissue sections, organs, and whole organisms.

Development of stereo-taxic and other apparatus for neurosurgical procedures.

Investigation of muscle control by ordered electro-stimulation.

PATTERN RECOGNITION

Investigation of the fundamentals of pattern recognition.

Application of pattern recognition techniques to the identification and classification of chromosomes, nerve fibres and specific areas on geological survey maps.

BIRD DISPERSAL BY MICROWAVE RADIATION

Investigation of the effect of low-intensity microwave radiation on the behaviour of birds on the ground and in the air, to determine the practicability of using microwave radiation for dispersing birds on airfields and from the flight path of an aircraft.

ENGINE LABORATORY

FREE PISTON ENGINES

Study of free piston engine and its applications. Use of simulation techniques to study alternate applications of free piston engine.

GAS TURBINE CYCLE ANALYSIS

Modifications to design-point cycle program, to handle afterburner and nozzle calculations for advanced turbofan engines.

DUCTED FAN AERODYNAMICS

Aerodynamic performance study of highly loaded ducted fans, with particular reference to inlet and outlet distortion phenomena as encountered typically by VTOL aircraft. Analytic study of the flow through a short compressor that operates with non-uniform inflow and outflow conditions.

V/STOL NOISE STUDIES

Study of the mechanism of the generation and suppression of noise produced by ducted fans for VTOL aircraft with and without cross-flow. Identification of the noise sources and relating the strength of the sources to the physical parameters of the system. Studies of possible layouts for an engineering acoustic facility.

IN-FLIGHT THRUST METER FOR JET ENGINES

An investigation concerned with the development of a meter capable of indicating continuously the gross thrust of a jet engine, being carried out in conjunction with a Canadian electronics firm. Preliminary assessments of results from sea level static tests with the development version of the instrumentation system are most promising. Arrangements are underway for altitude flight tests in a CF5 aircraft in co-operation with the CAF.

CENTRIFUGAL COMPRESSORS

Design and performance investigation of centrifugal compressors, including study of flow phenomena in oversize model impellers. Detailed study of devices for stabilizing the flow in the channels of a complete but simplified impeller is in progress. Fan and internal aerodynamics of Air Cushion Vehicles.

AXIAL COMPRESSORS

Preliminary analytical and experimental studies of small axial compressors.

AIR CUSHION VEHICLES

Studies are in progress on the airflow in various skirt-system, using several large scale models and an external air supply.

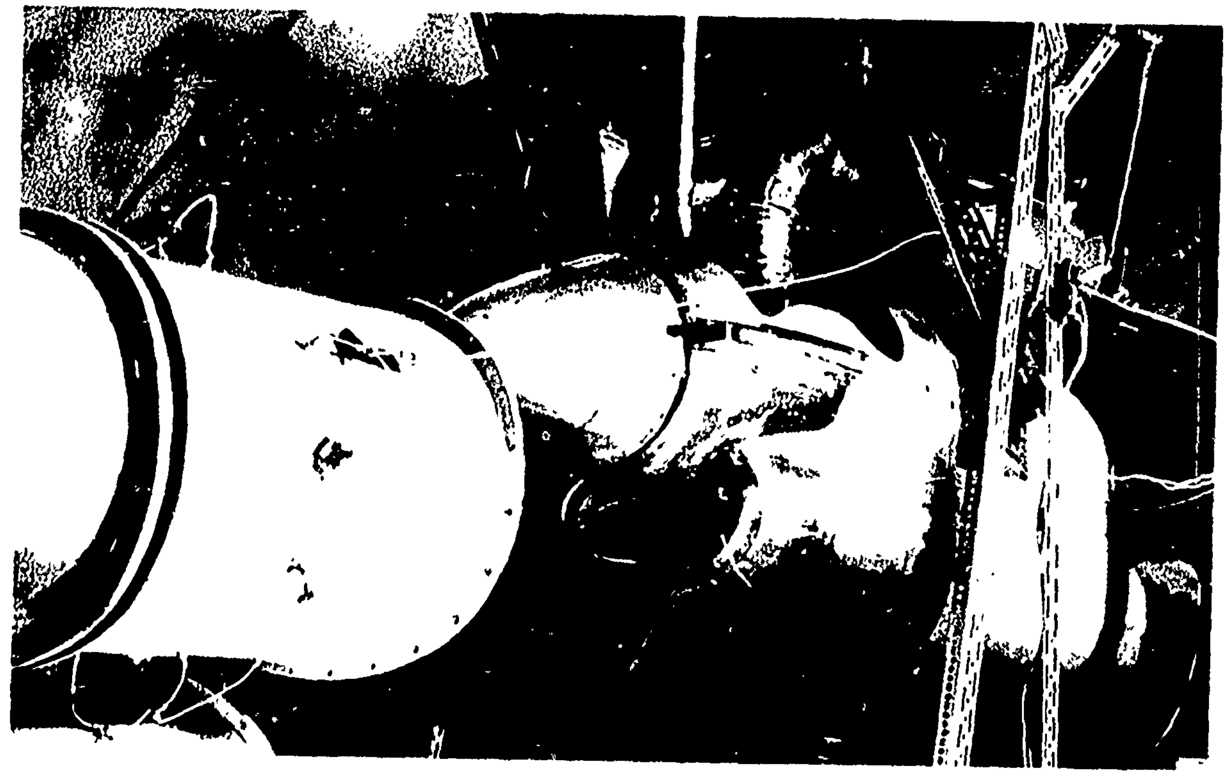
LOCOMOTIVE DIESEL ENGINE PROBLEMS

In co-operation with the Canadian National Railway and the Canadian Pacific Railway, an investigation of locomotive diesel engine problems, including those arising from the use of Athabasca Tar Sands synthetic crude oil as fuel.

Investigation of fuel additives suitable for reducing engine exhaust smoke and other air pollutants. Long runs for deposit assessment from barium antismoke additives.

FOAMED-CLAY MATERIALS

Investigation of novel light-weight foamed-clay building materials. Spent sulphite liquor, from the pulp mills, has been used as a foaming agent to produce a very stable liquid foam with common clays that, after drying and firing, gives a cellulated ceramic product. While the material has been developed primarily as a light-weight aggregate, it is felt that it may have many other uses. Patent application has been filed and the process has been offered to Canadian Industry for further development and production. There have been some interesting new technical developments aimed at improving the product, and some Canadian manufacturers are looking into the possibilities of commercial production.



UNITED AIRCRAFT PT6A-41 ENGINE INSTALLED FOR ICING TESTS IN NO. 4 TEST CELL

(BYPASS AIR DUCT REMOVED TO EXPOSE ENGINE COWL)

ENGINE LABORATORY
DIVISION OF MECHANICAL ENGINEERING

ENGINEERING ACOUSTIC FACILITY

A Task Force, under the aegis of the Associate Committee on Propulsion, has been established to examine the technical requirements and projected utilization of a facility in which to conduct acoustic studies of engineering equipment including gas turbine engines and their components. (Reference DME/NAE Q.B. 1971(4) Feature Article).

FLIGHT RESEARCH LABORATORY

DESIGN AND DEVELOPMENT TESTING OF A CRASH POSITION INDICATOR FOR HELICOPTERS

Experiments on models, supplemented by theoretical analyses, are being conducted for the purpose of evolving an improved crash position indicator for helicopters.

AIRBORNE REMOTE SENSING OF MAGNETIC PHENOMENA

Experimental and theoretical studies relating to the further development and use of magnetic airborne detection equipment. Equipment under development is installed on a North Star aircraft, which is used as a flying laboratory and for preliminary surveys requested by various Government Departments and other agencies.

INVESTIGATION OF FLYING QUALITIES AND CONTROL SYSTEM REQUIREMENTS APPLICABLE TO V/STOL AIRCRAFT

Airborne simulation techniques, using helicopters equipped to provide variable stability and control properties, are being employed to explore the effects of the numerous parameters involved and to produce data that are directly applicable for design purposes. Specific investigations are also being conducted for aircraft manufacturing firms and other agencies. Whenever possible direct comparisons are made between results obtained using the helicopter equipped as an airborne simulator and those obtained on actual VTOL and STOL aircraft. A Bell 47G3B1 helicopter with variable characteristics in four degrees of freedom is used for current research. A Bell 205A1 helicopter is being developed as an airborne simulator with variable characteristics in six degrees of freedom.

INVESTIGATION OF ATMOSPHERIC TURBULENCE

A T-33 aircraft, equipped to measure wind gust velocities, air temperature, wind speed, and other parameters of interest in turbulence research, is being used for several investigations. These include measurements at very low altitude, in clear air above the tropopause, in the neighbourhood of mountain wave activity, and near storms. Records are obtained on magnetic tape to facilitate data analysis. Clear air turbulence detection methods are also being investigated. The aircraft also participates in co-operative experiments with other Canadian and foreign research agencies. A second T-33 aircraft is used in a supporting role for these and other projects.

AIRCRAFT OPERATIONS

Various studies relating to aircraft operations are made from time to time. These may involve such matters as the provision of technical assistance during accident investigations, the analysis of particular aspects of aircraft behaviour in operations, or the preparation of recommendations on flight recorder requirements and specifications.

INDUSTRIAL ASSISTANCE

Assistance is given to aircraft manufacturers and other companies requiring the use of specialized flight test equipment or techniques.

INVESTIGATION OF SPRAY DROPLET RELEASE FROM AIRCRAFT

Theoretical and experimental studies of spray droplet formation are being conducted. Flight experiments utilize a Harvard aircraft modified to carry external spray tanks.

AUTOMOBILE CRASH DETECTOR

There is a need for a sensing device to activate automobile passenger restraint systems in incipient crash situations. Investigations are in progress to determine the applicability of C.P.I. technology to this problem.

ENVIRONMENTAL MEASUREMENTS

At the request of the Department of the Environment an instrumented T-33 aircraft is being used to acquire atmospheric data at low altitudes as part of Canadian contribution to the International Field Year of the Great Lakes.

Gas chromatograph equipment is being installed in a Beech 18 aircraft for measurements of pesticides in the atmosphere in the vicinity of spraying operations.

FUELS AND LUBRICANTS LABORATORY

HYDROGEN-OXYGEN ENGINES

Investigation of heat transfer in a 500-lb thrust rocket combustion chamber using a water-cooled chamber burning hydrogen and oxygen.

Testing of different types of rocket propellant injection plates.

Installation and investigation of a small regeneratively cooled rocket combustion chamber.

FUNDAMENTAL STUDIES OF FRICTION, LUBRICATION, AND WEAR PROCESSES

Investigations of friction and wear processes including the mechanism of adhesion between non-conforming metal surfaces and the processes involved with transferred films of solid lubricants.

Theoretical and experimental studies of a modified type of hydrodynamic thrust bearing and a theoretical study of a novel form of gas bearing.

PRACTICAL STUDIES ON LUBRICATION, FRICTION, AND WEAR

Assessment of wear in shotgun barrels with shot manufactured from different materials.

A co-operative program for the assessment of instrument oils and lubricant surface coatings in the bearings of miniature rotating electrical components.

COMBUSTION RESEARCH

Experiments on fuel spray evaporation

EXTENSION AND DEVELOPMENT OF LABORATORY EVALUATION

Development of new laboratory procedures for the determination of the load carrying capacity of hypoid gear oils under high speed conditions and under low speed high torque conditions.

PERFORMANCE ASPECTS OF FUELS, OILS, GREASES, AND BRAKE FLUID

Co-operative investigation covering used oil analysis and inspection of engines from Ottawa Transportation Commission buses to establish realistic oil and filter change periods.

Evaluation of used oils from railroad diesels to establish suitable test methods and condemning limits.

Investigation of laboratory methods for predicting flow properties of engine and gear oils under low temperature operating conditions.

Investigation of laboratory methods for predicting low temperature flow properties of diesel and heating fuels and assessment of their suitability.

Evaluation of methods for determining undissolved water content of aviation turbine fuels.

Development of a laboratory method for evaluating the shear stability of multigrade motor oils.

Determination of fuel system icing inhibitor in aviation turbine fuels.

Performance evaluations on domestic furnace fuel oil filters.

Diesel fuel system icing studies.

Investigation of the performance of synthetic hypoid gear lubricants.

Co-operative investigation covering test procedure for the evaluation of thermal oxidation stability of hypoid gear lubricants.

Evaluation of performance of experimental engine lubricants to determine their effect on ring sticking, wear, and accumulation of deposits under high speed, supercharged conditions.

Evaluation of smoke reduction in diesel engine exhaust by fuel additives.

Development of a laboratory method for the evaluation of oil performance in air-cooled two-stroke engines.

MISCELLANEOUS STUDIES

The preparation and cataloguing of intra-rea spectra of compounds related to fuels, lubricants, and associated products.

The application of Atomic Absorption spectroscopy to the determination of metals in petroleum products.

Investigation of the stability of highly compressed fuel gases.

Adsorption and decomposition of nitro-compounds on platinum.

Analytical techniques for analysis of engine exhaust emissions.

GAS DYNAMICS LABORATORY

V/STOL PROPULSION SYSTEMS

A general study of V/STOL propulsion system methods with particular reference to requirements of economy and safety.

Investigation of a vectored lift/thrust engine arrangement involving a shrouded fan driven by a partial admission turbine.

Experimental investigation of a pod-mounted VTOL fan for studies including the effects of flow of distortion in cross-flow and shroud thrust effects for several fans in a row.

An experimental study of tunnel wall interference effects from models exhausting jets of air at angle to the normal tunnel flow direction.

INTERNAL AERODYNAMICS OF DUCTS

An experimental study of the internal aerodynamics of ducts, bends, and diffusers with particular reference to the effect of entry flow distortion in geometries involving changes of cross-sectional area, shape, and axial direction.

HYDROSTATIC GAS BEARINGS

Studies of hydrostatic gas bearings to develop reliable methods of predicting bearing performance for a range of conditions and configurations, and to evolve suitable techniques for the satisfactory application of this type of bearing in situations where the special properties of gas bearings recommend their use.

SHOCK PRODUCED PLASMA STUDIES

A general theoretical and experimental investigation of the production of high temperature plasma by means of shock waves generated by electromagnetic and gasdynamic means, and the development of diagnostic techniques suitable for a variety of shock geometries and the study of physical properties of such plasmas.

HIGH PRESSURE LIQUID JETS

Water Jets ranging in size from 0.002 inch to 0.015 inch, generated by pressures in the range of 10,000 to 100,000 psi, are capable of cutting materials such as paper, cloth, plastics, wood, masonry, and even some metals.

Laboratory work is directed towards commercial exploitation of this phenomenon by various industries (e.g. paper, lumber, leather, garments, plastics, etc.) and to the detailed study of the phenomenon itself in order to improve the efficiency of the process. Experimental studies are also directed towards the production of intermittent jets for obtaining higher stagnation pressures.

INDUSTRIAL PROCESS, APPARATUS, AND INSTRUMENTATION

There is an appreciable effort, on a continuing basis, directed towards industrial assistance. This work is of an extremely varied nature and, in general, requires the special facilities and capabilities available in the laboratory.

Current co-operative projects with manufacturers include:

(a) Flow studies of industrial flue systems.

(b) Flow problems associated with industrial gas turbine exhaust systems.

(c) Lifting fan studies for VTOL applications.

(d) Ventilation of railway tunnels.

(e) Marine turbine exhaust ducting system.

(f) Fan engine exhaust vectoring systems.

HEAT TRANSFER STUDIES

Laboratory work continues on the characteristics of thermosiphons for application to (a) computer cooling, (b) air-to-air heat exchangers for air conditioning applications.

HIGH SPEED AERODYNAMICS LABORATORY

CONTROL OF A TURBULENT BOUNDARY LAYER IN A THREE-DIMENSIONAL SHOCK WAVE/BOUNDARY-LAYER INTERACTION

The 5-inch × 5-inch blowdown wind tunnel is in use to investigate the three-dimensional interaction between a glancing oblique shock wave and a turbulent boundary-layer flow along a flat wall at freestream Mach numbers of 2 and 4. Measurements of wall static pressure, Mach number, total temperature distributions through the viscous flow, and oil streak surface flow visualization have been completed. In a second phase, the optimum momentum requirements and angular setting of a wall jet relative to the interaction region to remove the three-dimensional separation will be determined.

THEORETICAL TWO-DIMENSIONAL TRANSONIC FLOW STUDIES

Different programs for supercritical flow calculations are being tested numerically in order to reduce the required computer time.

SHOCKLESS TRANSONIC AIRFOIL TESTS

Further tests of the shockless lifting airfoil designed by Garabedian and Korn has been carried out, this time with a top and bottom wall porosity of 20.5% (tests previously reported were at 6% porosity). Of particular interest was the airfoil characteristics in off-design conditions, in regions of flow separation and buffet characteristics.

TWO-DIMENSIONAL WALL-INTERFERENCE EFFECTS

Currently some calculations are made to evaluate the effects of flow curvature induced by the wind tunnel walls on the airfoil pressure distribution. The evaluated corrections to the lift and moment coefficients will be compared with the conventional theory.

THE SOLUTION OF ELLIPTIC EIGENVALUE PROBLEMS BY THE METHOD OF LINES

Using the method of lines technique, solutions have been obtained for the Helmholtz equation in a square and in an L-shaped region made of three unit squares. The first seven eigenvalues (symmetric) are found in the former case and the first five in the latter case. Accuracy is very good for the smaller eigenvalues and is about 1% for the higher eigenvalues.

A paper is to be presented at the First European Conference on Computational Physics.

NEW DATA SYSTEM

A new data acquisition system has been commissioned for the 5-foot blowdown wind tunnel. The system is based on a Honeywell DDP-516 computer having 16,000 words of memory and equipped with a serial multiplexer and an analogue to digital converter.

The system is equipped with 30 analogue channels which can be sampled at a rate of up to 250 samples per channel per second. Full scale resolution is ±16,000 counts and maximum sensitivity for full scale is 5 millivolts. The overall system accuracy is about ±0.15% of full scale at 3 sigma (99.7%).

During a wind tunnel run data is recorded in parallel on a drum storage unit and an IBM compatible magnetic tape transport. At the end of the run the data on tape is automatically verified against the drum and corrected if necessary. Quick look data is presented for all channels in serial form against a compressed time base on a high speed 2 pen strip chart recorder and then selectively plotted on an X-Y plotter. Final reduced data is presently obtained by processing the magnetic tape on NRC's IBM 360-67 computer.

COMPUTER PROGRAMMING FOR REDUCTION OF WIND TUNNEL TEST DATA

Introduction of the new, high speed, Data Acquisition System necessitated a re-evaluation of the data reduction procedures which had been used previously.

The very large increase in the volume of data obtained during a wind tunnel run, the result of a combination of the increased data sampling rate and the ability to combine in one run several different types of measurements which previously required separate runs, presented some unique problems.

The data reduction programs have been written in the Fortran language, using the approach of having many separate subroutines, each to perform a specific function. This approach has proved most satisfactory as it allows great flexibility in the compilation of a data reduction program for a specific test requirement. Development of further subroutines is continuing.

All data processing is via the IBM 360-67 Time Sharing System computer at the NRC Computation Centre.

EXHAUST STACK MODEL TESTS

Some model tests have been made on a 1/36-scale model of the fixed diffuser and stack of the 5-foot × 5-foot tunnel to obtain some information on the efficacy of schemes for reducing the upward penetration of the outflow.

The most attractive scheme evolved for reducing the vertical flow is a radially vaned flat topped deflector placed over the top of the stack but this may introduce unpleasant high frequency noise at ground level. Further work is required.

TESTS IN THE 5-FOOT × 5-FOOT BLOWDOWN WIND TUNNEL FOR OUTSIDE ORGANIZATIONS

McDONNELL-DOUGLAS CORPORATION, Long Beach, California

A previously tested wing profile (10-inch chord) was tested in the 15-inch 2-D test section for comparison purposes. Balance measurements, wake drag data and pressure scans were taken over a wide range of Mach numbers at fixed Reynolds number. Data is to be compared with that previously obtained for a similar section using an aspect ratio 6 (instead of 1.5) model.

DREV, Valcartier, Quebec

In a previous test series, the aerodynamic characteristics of a wind tunnel model employing wrap-around fins were investigated for the Defence Research Establishment, Valcartier. The present tests were undertaken with the same model in order to rectify anomalies and supplement deficiencies uncovered during analysis of the original test data.

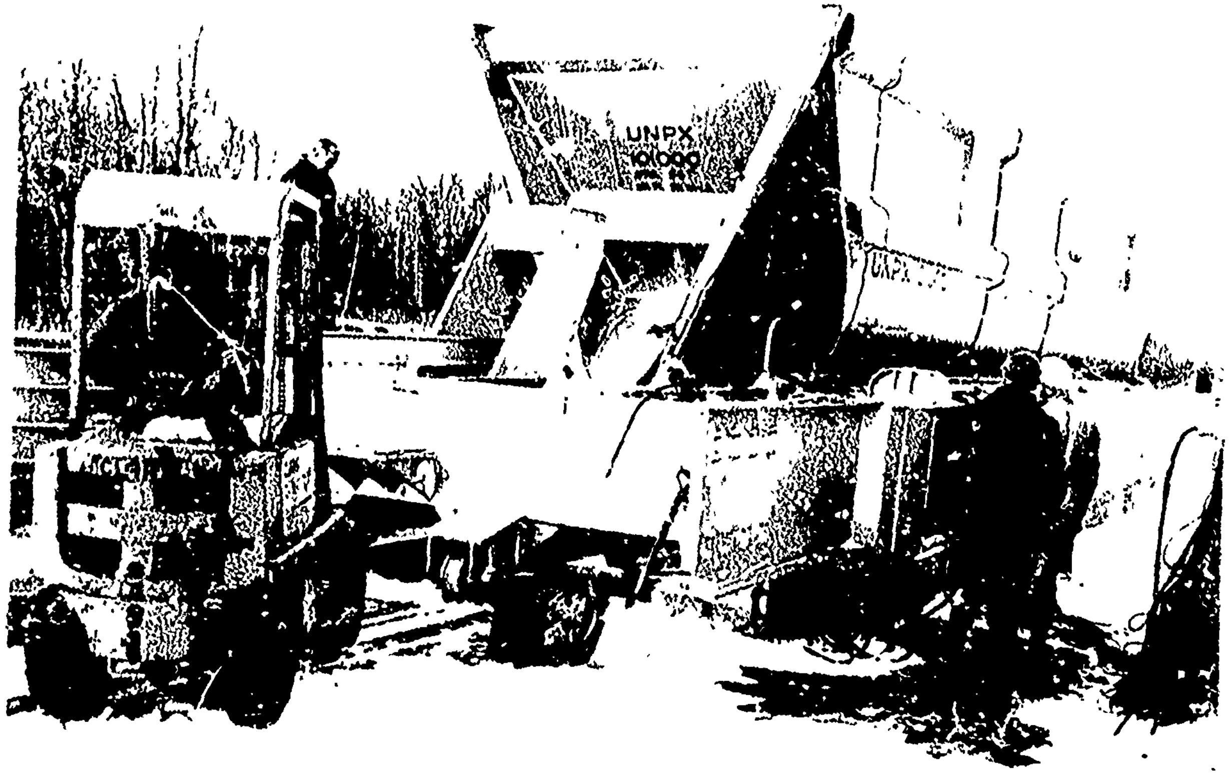
SAAB-SCANIA, Sweden

Preparations for an extensive investigation of the drag and stability characteristics of a 1/30-scale aircraft model were made. Special efforts were directed towards the problem of balance temperature drift and a satisfactory method of performing combined pitch-yaw runs.

HYDRAULICS LABORATORY

ST. LAWRENCE SHIP CHANNEL

Under the sponsorship of the Ministry of Transport, a study to improve navigation along the St. Lawrence River, using hydraulic and numerical modelling techniques.



RAILWAY CAR UNDERGOING STRENGTH TESTS IN THE INSTRUMENT SECTION'S SQUEEZE FRAME AT THE RAILWAY ENGINEERING LABORATORY AT UPLANDS.

INSTRUMENTS LABORATORY
DIVISION OF MECHANICAL ENGINEERING

WAVE RECORDER DEVELOPMENT

Development of staff gauges. Evaluation of other types of wave recorders: accelerometers, pressure transducers, and so forth.

WAVE DIRECTION STUDY

Field investigation to study the direction of wave energy in a confused sea as a function of wind direction.

NUMERICAL SIMULATION OF RIVER AND ESTUARY SYSTEMS

Specific applications to the St. Lawrence River, Fraser River, Ottawa River.

EXPERIMENTAL AND THEORETICAL INVESTIGATION ON DENSITY - STRATIFIED FLOWS

Applications to thermal pollution, oil slick propagation and containment, selective withdrawal from reservoirs.

INVESTIGATION ON TURBULENT DIFFUSION IN WAKE FLOWS

Experimental studies carried out in wind tunnel with possible extension to diffusion processes in rivers.

DEVELOPMENT OF SPECTRAL ANALYSIS PROGRAMS

For use in the analysis of wave records and on-line analysis of turbulent diffusion data produced in the laboratory.

KINCARDINE HARBOUR MODEL

Hydraulic and numerical model study of wave refraction, diffraction and reflection patterns.

WAVE FORCES ON OFF-SHORE STRUCTURES

Flume study to determine design criteria for off-shore mooring structures.

INSTRUMENTS LABORATORY

COUNTING ACCELEROMETER

Development of a force-balance type transducer suitable for both airborne and ground use and manufacture of a prototype punched paper recorder for use with this transducer as a self-contained statistical gathering system.

RAILWAY IMPACT RECORDER

Evaluation of results of preliminary road trial of our self-contained railway ride environment recording system.

FREIGHT CAR STUDIES AND TRAIN DYNAMICS

Continuation of study of freight car truck stability (hunting) and steering characteristics.

Design and development of a force transducer proposed for the measurement of tread and flange induced rail forces, both for full-scale and 1/12-scale rails.

Study of scale effects in rail vehicles, both for straight and curved track, on test rigs adapted to an existing centrifuge.

Strength tests on Canadian-designed and built freight cars. (See attached photo).

Design study of the requirements for a railway car roller test rig.

Provision of instrumentation and technical assistance to a Canadian railway in measuring truck (bogie) stiffness, locomotive tractive effort and tunnel heating effects.

AIRCRAFT NOISE PROBLEM

Continued preparation of control and data processing programs for a prototype noise monitoring and recording system to be installed by the Ministry of Transport at a major Canadian airport.

MECHANICAL AIDS TO SURGERY

Endurance tests totalling some 55,000,000 cycles of operation of a form of experimental venous valve are continuing.

Continued technical support to two local and one Vancouver hospital for clinical surgery and Departments of Experimental Surgery, in organ transplant procedures, arterio-venous surgery.

Aid to industry in preparation for commercial manufacture of the NRC vascular suturing instrument and also consumable components of the pigmentation injector.

Design and construction of a vascular suturing instrument for vessels 6-8 mm. diameter.

In collaboration with the Vancouver General Hospital, a modified form of external tension-relieving "splint" for counteraction of eviscerating forces and prevention of dehiscence of incisions closed with very low tensile strength suture material, was made. Evaluation in experimental surgery is in hand.

Consideration of a new form of artificial knuckle joint.

GRAVITY WATER WAVE GAUGES

Development and construction of one unit based on the NRC prototype, step-type, wave staff with solid state sensing and including time code generation and control, and construction of two further similar units.

Prototype transmission line, continuous-type, wave staff, completed and field trials conducted in Lake Ontario.

Development of an accelerometer-type wave gauge with radio link for deep water wave measurements using free floating buoy. Calibration trials against NRC step-type wave staff in Lake Ontario made.

Preparation of reports on capacitance-type wave gauges, transmission line-type wave staff, step-type wave staff, wave pressure sensors and wave accelerometer.

INDUSTRIAL INSTRUMENTATION

Investigation of problems reported by pulp and paper industry, in regard to mill operation of a new commercial form of consistency meter.

DATA ACQUISITION SYSTEMS

Evaluation of the merits of various forms of portable data terminals for use both with the IBM 360 and the Interdata Model 4.

Development of a special hardware and software package to aid in the on-line analysis of digital data generated in strength tests on freight cars.

Development of a mini-computer program package to perform preliminary statistical analysis of analogue data accumulated by the railway impact recorder.

LOW SPEED AERODYNAMICS LABORATORY

AERONAUTICAL WIND TUNNEL TESTS FOR OUTSIDE ORGANIZATIONS

During the quarter a series of wind tunnel tests was carried out in the 30-foot wind tunnel for Douglas Aircraft (Canada) and in the 6-foot × 9-foot tunnel for United Aircraft of Canada and DeHavilland (Canada).

INDUSTRIAL AERODYNAMIC TESTS FOR OUTSIDE ORGANIZATIONS

In the 15-foot vertical tunnel an elastically mounted model of an H-beam section with perforated web was used to investigate wind-induced oscillations for the Dominion Bridge Co., and in the 3-foot × 3-foot tunnel dynamic tests of stranded conductor models were begun for Alcoa.

THE WAKES OF TALL BUILDINGS

The results of velocity and turbulence measurements made behind arrays of building models in the 30-foot tunnel, in the presence of artificially generated shear flow, are now being analysed.

WAKE GALLOPING

An experimental program is continuing, currently in the 15-foot vertical tunnel, to investigate the wind-induced oscillations of a bundle of four transmission line conductors. Parallel linear and non-linear analysis is being attempted, using steady force test measurements made previously.

THE EXTERNALLY-BLOWN JET FLAP

The first phase of an experimental investigation of the externally-blown flap STOL scheme has been completed in the 6-foot × 9-foot tunnel, and results are being analysed. The model employed the exhaust of a simulated fan engine, directed through the flap assembly of a typical, double-slotted two-dimensional flapped aerofoil.

WIND TUNNEL TECHNIQUES

The investigation of a moving-belt ground board was continued in the 3-foot × 3-foot tunnel to determine the effect of belt length upstream and downstream of a jet flap model, on the measured lift, drag and pitching moment of the model close to the belt.

FLUIDICS

The experimental program to improve the external configuration of the NRC fluidic velocity sensor has been completed, and uniform characteristics have now been obtained in production models. An investigation of the internal nozzle configuration, to provide improved performance, has begun. A prototype industrial fluidic densitometer has been constructed and is being evaluated.

NUMERICAL METHODS

An investigation is being carried out to adapt and develop surface-element computer programs for the calculation of pressure distribution on axially symmetric bodies with openings (such as jet nacelles) at an angle of attack. One of the adaptations allows for induced effects of entrainment into the exit jet. Improvement of the computational accuracy is the focal point of the current activities.

LOW TEMPERATURE LABORATORY

LOW TEMPERATURE PROBLEMS IN RAILWAY OPERATIONS

Analytical and experimental work, conducted under the auspices of the Associate Committee on Railway Problems, Sub-Committee on Climatic Problems, including the low temperature performance of air brake systems, aftercooler, design and development, an investigation into rail switch malfunctions under severe climatic conditions, evaluation of various rail switch heater systems. Pulse jet powered rail switch heaters have been investigated and are being developed for field applications. Switch protection by passive means is being pursued as a long range project. A new switch design is being fabricated for evaluation in snow and ice conditions.

HELICOPTER DE-ICING

A study of helicopter icing protection involving the evaluation of various systems (thermal, fluid, and self-shedding materials) and the development of de-icing control systems including ice detectors. The principles for a dynamic ice detector with high sensitivity to be used on helicopters are being investigated.

AIRCRAFT INSTRUMENTATION

The investigation of possible modes of failure for aircraft pitot heads under icing and snow conditions.

MISCELLANEOUS ICING INVESTIGATIONS

Analytical and experimental investigations of a non-routine nature, and the investigation of certain aspects of icing simulation and measurement.

TRAWLER ICING

In collaboration with Department of Transport, an investigation of the icing of fishing trawlers and other vessels under conditions of freezing sea spray, and of methods of combatting the problem.

LOW TEMPERATURE APPLICATIONS IN MEDICAL ENGINEERING

Design of a shunt valve for cerebrospinal fluid in hydrocephalus. The device can be adjusted after implantation without surgical intervention.

Development of a capsule for telemetry of intracranial pressure. A special feature is its permanent, radio-transparent, moisture-impermeable casing.

An investigation into the hypothermic preservation of organs with perfusion by blood substitutes.

AIR CUSHION VEHICLE ENVIRONMENTAL PROBLEMS

A study has been started on the deposition of snow on sections representing possible tracks for guided ACV's. Snow and ice deposits are being measured and recorded during each winter storm.

A study of snow removal by unconventional methods is being undertaken for high speed transit systems.

MARINE DYNAMICS AND SHIP LABORATORY

WAVE MEASUREMENT AND STRESS ANALYSIS

A stratified sample of 323 wave records from the North Atlantic have been analyzed and their spectra examined (LTR-SH-118). Further studies of these data are in progress. Work is to be continued in analyzing wave data already collected by the laboratory staff in both the Pacific and North Atlantic Oceans.

The Laboratory Wave Buoy Systems are being improved as a result of experiment and theoretical work.

OCEANOGRAPHIC SUB-SEA BODIES

Designing and manufacturing experimental bodies.

DEEP DIVING SUBMARINE

Propeller system investigations.

DEEP DIVING SUBMARINE TENDER

New design - model studies in progress.

LARGE TANKERS

Model resistance and propulsion experiments in progress.

EAST COAST FISHING VESSELS

Particular seakeeping information, with special emphasis on capsizing in a seaway, is being obtained on two models of actual vessels. The studies are being extended to investigate general dynamic stability requirements.

HIGH-SPEED TWIN-HULL VESSEL

A model of this vessel is nearing completion, experiments are to be carried out in order to finalize the design details. Particular emphasis will be made regarding seakeeping behaviour. The vessel to be built is of the order of 70 tons displacement and the design has potential for expansion to very interesting larger size vessels.

STRUCTURES AND MATERIALS LABORATORY

FATIGUE OF METALS

Studies of the basic fatigue characteristics of materials under constant and variable amplitude loading; fatigue tests on components to obtain basic design data; fatigue tests on components for validation of design; studies of the statistics of fatigue failures; development of techniques to simulate service fatigue loading.

RESPONSE OF STRUCTURES TO HIGH INTENSITY NOISE

Study of excitation and structure response mechanisms; study of panel damping characteristics and critical response modes; investigation of fatigue damage laws; industrial hardware evaluation; investigation of jet exhaust noise.

AIRCRAFT AND INDUSTRIAL HYDRAULICS

Cognizance of state of the art maintained in all branches of hydraulics and pneumatics; physical properties of hydraulic fluids and aspects of high pressure, high velocity fluid phenomenon under continuous study.

OPERATIONAL LOADS AND LIFE OF AIRCRAFT STRUCTURES

Instrumentation of aircraft for the measurement of flight loads and accelerations; fatigue life monitoring and analysis of load and acceleration spectra; full-scale fatigue spectrum testing of airframes and components.

ELECTRON FRACTOGRAPHY

Qualitative determination of fracture mechanisms in service failures; fractographic studies of fatigue crack propagation rates and modes.

RESEARCH ON PROTECTIVE COATINGS FOR REFRACTORY METALS

Investigation of coating compounds for protection of refractory metal substrates at high temperatures; methods and techniques of coating deposition; study of interface diffusion rates and products; evaluation of the oxidation properties of coated coupons.

MECHANICS AND THEORY OF STRUCTURES

Study of coupled flexural-torsional vibration of uniform beams; study of dynamics of a tensioned cable with moving constraints; short time response of coupled fluid and elastic structures; investigation of static stresses and displacements around cut-outs in cylindrical shells.

FLIGHT IMPACT SIMULATOR

Simulator developed and calibrated to capability of accelerating a 4-lb mass to velocity of 1000 ft/sec; operation on year-round basis achieved and includes use of temperature controlled enclosure from -40° to +130°F; in addition to airworthiness certification program includes assessment of resistance to impact for materials and structural design for most types of viewing transparencies.

CALIBRATION OF FORCE AND VIBRATION MEASURING DEVICES

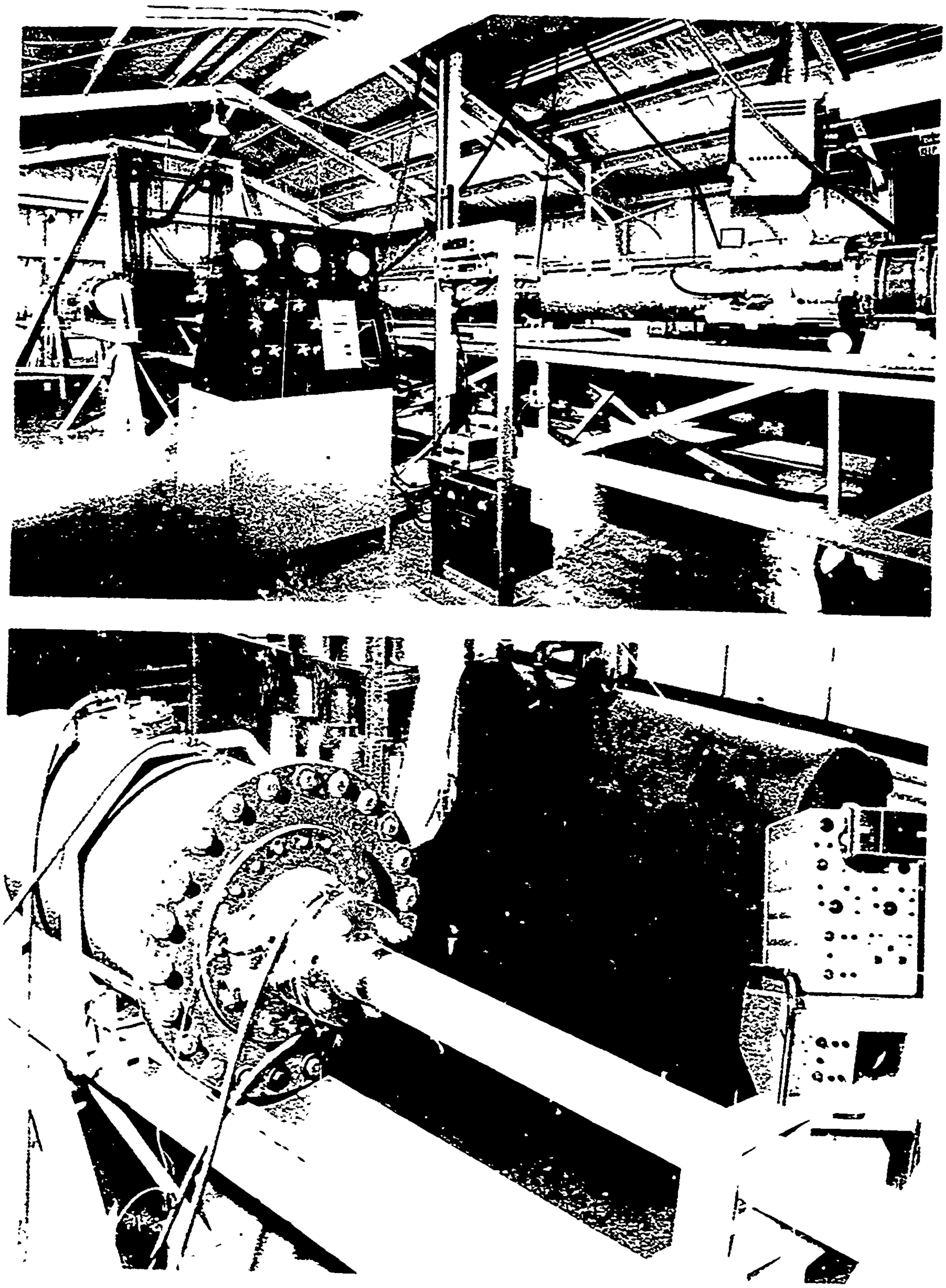
Facilities available for the calibration of government, university, and industrial equipment include deadweight force standards up to 100,000 lb, dynamic calibration of vibration pick-ups in the frequency range 10 Hz to 2000 Hz.

COMPOSITE MATERIALS

Studies of composites including resins, crosslinking compounds, polymerization initiators, selection of matrices and reinforcements, application and fabrication procedures, material properties, and structural design.

FINITE ELEMENT METHODS

Development and application of refined finite elements for plate bending, plane stress, and shallow shells; application of finite elements to flutter, shell dynamics, plate buckling, and stiffened plate dynamics; development of a general triangular deep shell finite element.



RECENT ADDITIONS TO THE FLIGHT IMPACT SIMULATOR INCLUDE HYDRAULIC BREECH MECHANISM (ABOVE, RIGHT) AND LOWER VELOCITY GUN FOR SMALL BIRDS (BELOW)

STRUCTURES AND MATERIALS LABORATORY
NATIONAL AERONAUTICAL ESTABLISHMENT

MOTOR VEHICLE SAFETY

The mathematical model of the redirection of a vehicle by a cable barrier has been validated experimentally and effort is now being concentrated on the development of a facility for the dynamic measurement of the inertial properties of automobiles by suspending them on air bearings.

In collaboration with Ministry of Transport, Road and Motor Vehicle Traffic Safety Branch, studies to determine the performance of headlights in the driver passing task are being carried out. Work is continuing on vehicle defrosting. Work is also continuing on a system for studying driver performance and traffic quality by the analysis of automatically recorded vehicle control input and response data.

UNSTEADY AERODYNAMICS LABORATORY

HELIUM HYPERSONIC WIND TUNNEL

Two 11-inch diameter contoured nozzles (on long term loan from the U.S.) for Mach numbers 10 and 18 now available. Also available, a heater to provide small (100°F) increases in the stagnation temperature of the flow, and a variable incidence sector support for static force, moment, and pressure measurements on sting-mounted models.

DYNAMIC EXPERIMENTS ON CONES

Measurement of oscillatory characteristics of elliptic and circular cones at supersonic and hypersonic speeds, including a study of the effect of non-zero mean angle of attack.

ANALYTICAL STUDIES OF UNSTEADY FLOWS

Analysis of inviscid unsteady flow fields over elliptic cones in supersonic flows and over parabolic-arc aerofoils in hypersonic flows.

DYNAMIC VISCOUS PRESSURE INTERACTIONS

Analysis of the effect of boundary layer on unsteady pressure distributions on oscillating bodies in continuum hypersonic flow. Applications to wedges and cones.

GAS PHASE REACTION KINETICS

A physico-chemical study of the reactions of some constituents of the upper atmosphere, such as oxygen, nitrogen, and hydrogen atoms, to provide laboratory data in support of rocket experiments on upper atmospheric composition. Proposal available for a new method for the obsolute determination of the atomic concentration of oxygen and nitrogen in the 90-120 km region.

SCHLIEREN CAPABILITIES IN 30-INCH × 16-INCH WIND TUNNEL

Access port and window for optical flow diagnostics now available in the Mach 2 nozzle of the 30-inch × 16-inch wind tunnel. Study of possibilities to use optical systems for half-model experiments.

MOLECULAR LASERS

Preliminary study of CO_2 gasdynamic lasers. Construction of required components and of a low-power CO_2 electrical laser for diagnostic purposes.

SUPERSONIC DYNAMIC STABILITY EXPERIMENTS ON THE SPACE SHUTTLE

Study of static and dynamic interference effects on the dynamic stability of the space shuttle during abort separation. Measurement of the dynamic stability of the launch configuration with and without a simulated exhaust plume.

AIRBORNE PESTICIDE DETECTION

Development of a pesticide-in-air detection system for aerial surveillance.

PUBLICATIONS

The following unclassified reports were released during the quarter.

AERONAUTICAL REPORTS

LR-555 GAS TURBINE CYCLE CALCULATIONS: EXPERIMENTAL VERIFICATION OF OFF-DESIGN-POINT PERFORMANCE PREDICTIONS FOR A TWO-SPOOL TURBOJET WITH VARIOUS AIR BLEEDS.

M.S. Chappell and W. Grabe, Division of Mechanical Engineering, November 1971.

As part of a continuing program of gas turbine cycle calculations, the Engine Laboratory of the National Research Council of Canada has proposed a simplified method for calculating off-design-point performance of turbojet and turbofan engines, both at sea level static and at altitude flight conditions. This method specifically implies constancy of component efficiencies and linearity of corrected mass flow with corrected engine speed.

During a series of tests on a J-75 two-spool turbojet engine, experimental data were gathered at part-throttle conditions, and subsequently with compressor bleed extraction and with propelling nozzle area change.

In general, the calculation routine yielded very good predictions of the part-throttle performance of the datum engine. It was far less successful, however, in forecasting the effects of compressor bleed extraction, propelling nozzle area change, and combinations of these perturbations to the basic cycle.

LR-556 POTENTIAL FLOW CALCULATIONS FOR ARBITRARY AXISYMMETRIC BODIES.

R.J.A. Dufault and D.H. Henshaw, National Aeronautical Establishment, November 1971.

A very general method of calculation for incompressible potential flow about arbitrary axisymmetric bodies has been coded for a modern TSS computer system. Potential flow at any angle of attack can be computed with or without suction through the body surface - features which render the method of considerable interest for application to such bodies as jet engine nacelles. The coding is of general interest because of its logical arrangement as well as for the procedures used in the calculation of the elliptic integrals and the method of equation solution. The refinements to integrals for the singular elements are new.

LR-557 FLOW VISUALIZATION IN THE NATIONAL AERONAUTICAL ESTABLISHMENT'S WATER TUNNEL.

G.A. Dobrodzicki, National Aeronautical Establishment, February 1972.

This report is intended to demonstrate the utility of the Flow Visualization Water Tunnel in the field of experimental fluid dynamics and also provide guidance to its prospective users.

A brief description of the facility and its ancillary equipment is followed by a resumé of the Flow Visualization techniques.

To emphasize the diversity of subjects tested in the water tunnel, a list of typical experiments and a number of photographs are presented.

MECHANICAL ENGINEERING REPORTS

MP-56 EVALUATION OF FIRE RESISTANT LUBRICANTS FOR INDUSTRIAL GAS TURBINES.

L. Gardner and G. Moon, Division of Mechanical Engineering, November 1971.

The use of fire-resistant lubricants, of the phosphate ester type, in industrial gas turbines used for natural gas transmission is widely accepted. These fluids are more expensive than petroleum lubricants and a long service life is required to make their use economically viable. Preliminary laboratory screening of new candidate fluids for their ability to resist oxidative and thermal breakdown is a useful measure prior to field evaluation. Little previous work has been done to develop methods for measuring thermal and oxidative stability of phosphate esters and the present report describes the adaptation of two test procedures normally used for aircraft synthetic lubricants for this purpose. Test parameters were established using a long established proprietary phosphate ester fluid and then, using the same conditions, some fourteen candidate fluids were evaluated. In addition to the oxidation and thermal stability measurements, the fire resistance of all the fluids was measured using manifold ignition and low pressure spray tests.

MECHANICAL ENGINEERING REPORTS (Cont'd)

MP-57 THE WEAR AND DAMAGE OF SHOTGUN BARRELS WITH IRON AND NICKEL PELLETS OF VARIOUS HARDNESS.

C. Dayson and T. Maloney, Division of Mechanical Engineering, March 1972.

A second series of tests is described in which the wear and damage to the barrels of shotguns, from which iron, nickel and lead pellets were fired, was measured. As expected both the wear of the bore and the deformation of the barrel at the choke were less when soft nickel and soft iron pellets were fired than had been the case with harder pellets. Nevertheless both types of damage were still of an appreciable magnitude, indicating that these materials are not suitable for the manufacture of non-toxic pellets to replace lead. The results suggest that there is a definite relationship between the two types of damage and the relative hardnesses of the pellets and the barrel. A greater quantity of more precise data on softer shot materials will be needed to enable estimates to be made of barrel life that can be obtained with such materials.

TECHNICAL TRANSLATIONS

TT-1519 RADIO WAVES AND THE LIVING ORGANISM.
* $2.00

Yu. V. Sebrant and M.P. Troyanskii.
From Biologiya, Seriya 4, Moscow, 1969.

TT-1523 INTERPRETATION OF INTERNAL LATTICE DEFORMATIONS IN PLASTICALLY DEFORMED α-IRON.
* $1.50

F. Bollenrath, V. Hauk and W. Weidemann.
From Archiv fur das Eisenhuttenwesen, 38 (10): 793-800, 1967.

* The above translations are available from the Translation Section, NRC Library, Sussex Drive, Ottawa, Ontario, either on an exchange basis with libraries of government departments and universities or at the price indicated.

MISCELLANEOUS PAPERS

ABDELHAMID, A.N.† and SCHAUB, U.W. Unsteady Forces and Noise from Fan-in Wing Model in Cross Flow. Presented at the Gas Turbine and Fluids Engineering Conference and Products Show, San Francisco, California, March 26-30, 1972. ASME Paper 72-GT-92.

BIGU DEL BLANCO, J., ROMERO-SIERRA, C., TANNER, J.A. and BIGU, L. Progress Report on the Investigation of the Effects of MW Radiation on the Diffusion Rate of Electrolytes through Membranes. National Research Council of Canada, DME Lab. Tech. Report LTR-CS-73, January 1972.

BIGU DEL BLANCO, J., ROMERO-SIERRA, C., TANNER, J.A. and BIGU, L. Effects of Microwave Fields on the Rate of Flow and Mass Flux of Liquids Flowing Along Tubes of Small Diameter. National Research Council of Canada, DME Lab. Tech. Report LTR-CS-74, January 1972.

BUCK, L. Performance Data for the NRC Stressalyzer. National Research Council of Canada, DME Lab. Tech. Report LTR-CS-69, January 1972.

HADDOW, J.B.†† and HRUDEY, T.M. A Finite Strain Theory for Elastic-Plastic Deformation. Published Int. J. Non-Linear Mechanics, 1971, Vol. 6, pp. 435-450.

HADDOW, J.B.†† and HRUDEY, T.M. The Yield Condition of Flow Rule for a Metal Subjected to Finite Elastic Volume Change. Published Journal of Basic Engineering, Vol. 93, Series D, No. 4, December 1971, pp. 708-712.

HAMILL, P. and HAYES, W. Comme··s on a Gyro-Stabilized Monorail Proposal. National Research Council of Canada, DME Lab. Tech. Report LTR-CS-77, March 1972.

HAMILL, P. and KASVAND, T. Interim Report on an Automatic Chromosome Analysis System. National Research Council of Canada, DME Lab. Tech. Report LTR-CS-59, January 1972.

HAMILL, P. Preliminary Test Results with a Proposed Interactive Chromosome Analysis System. National Research Council of Canada, DME Lab. Tech. Report LTR-CS-72, February 1972.

HRUDEY, T.M. and HADDOW, J.B.†† Expansion of an Elastic-Plastic Spherical Shell with Finite Elastic Deformation. Presented at CANCAM Meeting, Calgary, May 1971. Published in Proceedings.

HUCULAK, P. Vision and the Automobile Headlamp. Published in the Canadian Journal of Optometry, Vol. 33, No. 3, December 1971.

IYENGAR, S. Experimental Damping-in-Pitch of Two Slender Cones at Mach 2 and Incidences up to 30°. National Research Council of Canada, NAE Lab. Tech. Report LTR-UA-19, January 1972.

JONES, D.J. Tables of Inviscid Supersonic Flow about Circular Cones at Incidence $\gamma = 1.4$. AGARDograph 137, Part III.

JONES, D.J. A Pressure Formula for an Inclined Circular Cone in Supersonic Flow, $\gamma = 1.4$. AIAA Journal, February 1972.

KASVAND, T. Computer Processing of Films of a Conical Object in a Wind Tunnel. National Research Council of Canada, DME Lab. Tech. Report LTR-CS-68, January 1972.

KASVAND, T. Computer-Aided Digitization of Operator-Selected Data in Pictures. National Research Council of Canada, DME Lab. Tech. Report LTR-CS-76, February 1972.

KRISHNAPPA, G., Lifting Fan Noise Studies with Superimposed Cross Flows. AIAA 10th Aerospace Sciences Meeting, San Diego, California, January 17-19, 1972. AIAA Paper No. 72-128.

LAU, J. and MacLEOD, D. Electrical Shock Tube with Curved End Wall. CASI Transactions, March 1972.

LEE, B.H.K. and WESTLEY, R. Effective Axial Source Distributions in a Choked Screech Jet. Presented at the Aero-Acoustics Section AIAA 10th Aerospace Science Meeting, held in San Diego, California, January 17-19, 1972. Published AIAA Paper No. 72-159.

LEQUOC, S., HAYES, W.F. and KWOK, C.G.K. Fluidic Heading Reference System. Fluidics Quarterly, Vol. 3, No. 4, Ann Arbor, Michigan, October 1971, pp. 16-29.

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OLSON, M.D. and LINDBERG, G.M. Dynamic Analysis of Shallow Shells with a Double-Curved Triangular Finite Element. Published Journal of Sound and Vibration, Vol. 19(3), 1971, pp. 299-318.

ORLIK-RUCKEMANN, K.J. and LABERGE, J.G. Dynamic Interference Effect on Dynamic Stability of Delta-Wing Shuttle in Abort Separation at $M = 2.0$. National Research Council of Canada, NAE Lab. Tech. LTR-UA-18, November 1971.

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† Carleton University.

†† University of Alberta.

MISCELLANEOUS PAPERS (Cont'd)

ORLIK-RÜCKEMANN, K.J., LABERGE, J.G. and HANFF, E.S. Experiments on the Dynamic Stability of the Space-Shuttle. NASA TM X-2506, February 1972, pp. 933-967.

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PLOEG, J. Spray Patterns of Nozzle for Fire Control in Navigation Locks. National Research Council of Canada, DME Lab. Tech. Report LTR-HY-24, March 1972.

PRANDLE, D. Model Study of Kincardine Harbour. National Research Council of Canada, DME Lab. Tech. Report LTR-HY-23, March 1972.

PRATTE, B.D. and KEFFER, J.F. The Swirling Turbulent Jet. Paper presented at Gas Turbine and Fluids Engineering Conference, San Francisco, California, March 29, 1972. (ASME publication).

SEWELL, R.T. An Investigation of Flight Loads Counting Methods and Effects on Estimated Fatigue Life. Presented at the National Business Aircraft Meeting of the SAE held in Wichita, Kansas, March 15-17, 1972. Published as SAE Paper No. 720305.

SEWELL, R.T. PLOT 4. Interdata Incorporated. Oceanport, New Jersey. Program for Interchange Program Library called "PLOT 4", accepted and assigned program No. IUG-147, 1972.

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WEIBUST, T. Monitoring, Recording Noise at Airports. Published in Canadian Controls and Instrumentation Magazine, January 1972.

WICKENS, R.H. The Trailing Vortex Wake Downstream of an External Flow Jet Flap. C.A.S.I. Journal, March 1972.

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KASVAND, T. Can We Teach Computers to See? Paper presented at First Canadian Remote Sensing Symposium, Ottawa, February 7-9, 1972.

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NOONAN, J.W. Bird Watching at 700 MPH. Address given to the Joint Meeting of CASI and SESA held in Ottawa, January 11, 1972.

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QUANBURY, A.O. A Computer Aided Study of Human Locomotion. Paper presented at the ACM-SIGGRAPH Symposium on the Application of Computer Graphics in Medicine, Pittsburgh, Pa., March 7-10, 1972.

TANNER, J.A. Bioengineering - A New Horizon for Engineers. Lecture presented to the Huron-Niagara Section of the American Society of Mechanical Engineers, Hamilton, March 8, 1972.

TANNER, J.A. Bioengineering - Bridging the Gap. Seminar presented to the Department of Engineering Science, the University of Western Ontario, London, Ontario, March 21, 1972.

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TEMPLIN, R.J. NRC and the Aerospace Industry. Talk given to the Department of Supply and Services Briefing to the Aerospace Industry, Ottawa, March 29, 1972.

WALLACE, W. The Role of Surfaces and Interfaces in Materials Engineering. Presentation at NRC Surface Science Seminar, held at Division of Chemistry, NRC, Ottawa, February 18, 1972.

FILM

PRANDLE, D. Tidal Propagation in the St. Lawrence River. Colour, sound, 16 mm. movie. National Research Council of Canada, DME Film No. 30.

AERONAUTICAL LIBRARY

Statistical Summary of Library Operations for the Quarter
January 1, 1972 to March 31, 1972

Documents accessioned	3,078
Cards added to the catalogue	11,798
Books received	231
Bound periodicals received	45
Loans to NRC staff (including Periodical circulation and Xerox and Microfiche copies supplied in lieu of loans)	6,674
Loans and distribution to outsiders	2,183
Total circulation	8,857
Information inquiries (quick reference)	3,316
Literature searches and bibliographies	265

NOTE: These summaries include statistics for the Uplands Branch of the Aeronautical Library.